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[656]

Competition by roads, waterways and airways.

(Continuation).

Great Britain.

By courtesy of the British Railway Clearing House, we publish hereafter a memorandum of the British Railway Companies showing developments in regard to competition and co-ordination between road and rail during the year 1935.

LEGISLATION.

Road Traffic Act, 1930.

There have been no alterations or amplifications of the above Act during the year 1935.

The provisions of the Act regarding the licensing of passenger road services continue to work smoothly; recent statistical information is contained in the Report of the Traffic Commissioners for the year ended 31st March, 1935.

A continued decrease in the number of small operators, mainly due to absorptions by larger companies is shown in the following figures :

At 31st December.	Number of operators owning :			Total number of vehicles owned by		
	up to 49 vehicles.	50 or more vehicles.	Total.			
	(1)	(2)	(3)	(1)	(2)	(3)
1932	6 193	114	6 307	19 854	26 604	46 458
* 1933	5 824	112	5 936	18 329	27 064	45 393
1934	5 608	115	5 723	17 664	28 082	45 746

* Revised figures contained in 1935 Report (see *Bulletin of the Railway Congress*, May 1935, p. 483).

It will also be seen that in 1934 the total number of vehicles slightly increased and this, together with an increase in average annual mileage per vehicle from 28 600 in 1933 to 29 300 in 1934, has led to an increase in total vehicle-miles of 33 000 000 or 2 1/2 %, and in receipts of £ 2 000 000 or 3 1/2 %. This increase has been influenced to a large extent by the replacement of trams by omnibuses.

While stage services, and to a smaller degree, tours and contract services, show increases in mileage and receipts, express services show a decrease in the last year of 4 000 000 miles and £ 300 000 receipts, which represents, to some extent, traffic recovered by the Railway Companies.

There have been no material alterations during the last year in the level of fares charged by road operators but certain of the Commissioners comment that stabilisation in services has not been reached and state that there has been no apparent diminution in applications for modification of licences, involving timetable alterations, or in applications for new services.

Road and Rail Traffic Act, 1933.

There have been no alterations or amplifications of this Act during the year 1935.

Wages in the road transport industry. — Steps have been taken during the past year to regulate the wages and conditions of employees in the goods road transport industry in consequence of the provisions of the Act.

Under section 93 of the Road Traffic Act, 1930, as amended and applied by section 32 of the Act of 1933 it is laid down in effect that the wages and conditions of employment in the road transport industry shall not be less favourable than those commonly recognised by employers and trade unions or, in the absence of such recognised rates and conditions, those observed by good employers in the neighbourhood. Conformity with such wages and conditions is made a condition of all « A » and « B » licences and thus any operator who fails to comply not only renders himself liable to prosecution but also to the loss of his licence.

Any organisation of persons engaged in the road transport industry may represent to the Licensing Authorities that the wages and conditions of any holder of an « A » or « B » licence are not satisfactory, and if the matter in dispute is not otherwise disposed of it shall then be referred to the Industrial Court. It is provided that this body in giving its decision shall have regard to any agreement of a joint body of employers and employees to which its attention is drawn. For the purpose of drawing up an agreement of such a nature there was set up in 1934 a National Joint Conciliation Board for the Road Motor Transport Industry (Goods) and this Board has issued recommendations which in its opinion form the basis of fair wages and conditions. These lay down minimum rates of wages, varying according to the laden weight of vehicles, and to the type of district where the driver is employed, i.e., whether an important industrial area, other industrial area or rural area, and provide for a 48-hour week, overtime rates and pay for holidays. Local Joint Conciliation Boards were then set up in each traffic area and on these has fallen the duty of basing local agreements on the recommendations of the National Board in the light of particular conditions in each area. After a considerable

amount of discussion and negotiation agreements have been completed in most areas and are in process of completion in the remainder.

There is evidence that responsible operators are already observing the terms of the agreements and pressure will no doubt be brought on others by the Licensing Authorities which will lead to general observance and to the elimination of the unfair advantage obtained by operators who are underpaying their drivers.

So far as the respective Railway Companies' road employees are concerned, their rates of pay and conditions of service are the subject of agreements between the Railway Companies and the Trade Unions.

Finance Act, 1935.

On and from 1st August, 1935, the customs duty on heavy oil for use by compression-ignition motor vehicles was increased from 1d. to 8d. per gallon and the scale of licence duties on such vehicles was reduced to that applicable to petrol-driven vehicles. As the duty on petrol is also 8d. per gallon, the two types of vehicle are now placed on a parity in regard to both licence and fuel duties, although the compression-ignition vehicle still retains the advantage over the petrol vehicle by reason of its higher rate of mileage per gallon of fuel.

Result of public enquiries held by licensing authorities insofar as the operation of the licensing system is concerned.

The policy followed by the Railway Companies for the first licensing period was to refrain from opposing applications to the extent set out in the Report for the year 1934.

Opposition to applications has mainly fallen upon the Railway Companies. In a comparatively few cases only has there been serious opposition as between road hauliers themselves. The Railway Companies' opposition can be said to have met with a considerable measure of success.

In the case of « B » licences granted, the Licensing Authorities have generally attached conditions restricting the operations of the applicants to the extent of their activities during the basic year.

At the 30th September, 1935, licences had been issued in respect of approximately 100 000 vehicles and 28 000 holders in Class « A », 55 000 vehicles and 35 000 holders in Class « B » and 305 000 vehicles and 150 000 holders in Class « C ».

Generally speaking, the decisions of the Licensing Authorities have been consistent, and the Railway Companies have exercised their right of appeal only in certain selected cases with the view of establishing principles for the guidance of the Licensing Authorities in the administration of the Act.

Appeals.

Under Section 15 of the Road and Rail Traffic Act, 1933, any person who :

a) being an applicant for the grant or variation of a licence, is aggrieved by the decision of the licensing authority on the application, or, in the case of a B licence, by any condition attached to the licence by the licensing authority; or

b) having duly made an objection to any such application as aforesaid, being an objection which the licensing authority is bound to take into consideration, is aggrieved by the decision of the licensing authority thereon; or

c) being the holder of a licence, is aggrieved by the revocation or suspension thereof,

may within the prescribed time and in the prescribed manner appeal to the Appeal Tribunal to be constituted under this Part of this Act.

The following major principles enunciated by the Appeal Tribunal are now being applied generally by the Licensing Authorities :

Statutory obligations of Railway Companies.

The Licensing Authorities refused an application by the Railway Company for an « A » Licence on the grounds that :

I. A Railway Company is on the same footing as any other applicant.

II. That the applicants (the Railway Company) had not shown that the work they proposed to do could not be done by other Carriers in the district.

An appeal was made to the Tribunal against this decision and succeeded on the following grounds :

a) That the Railways are in an exceptional position owing to their peculiar statutory obligations as to collection and delivery. If, therefore, the Railway Company can show that they could carry out these statutory obligations more efficiently with the licenses than without, their application should succeed, notwithstanding they will thereby abstract traffic from other carriers already engaged in carrying in the district intended to be served.

b) That the evidence had established that collection and delivery could be better co-ordinated at a particular point with the railway services and could be carried out more efficiently by the Railway Company with the vehicles owned by them and under their control, than by their employing others to do the work.

Established hauliers. — The maintenance of the statu-quo should be the aim in the first licensing period. The established haulier desiring to augment his tonnage should furnish proof that the increase is necessitated by general expansion of industry in the business or district.

New entrants. — The new entrant to the road transport industry must prove that there are persons ready and willing to employ him, and in addition must lead evidence sufficient to make out to the satisfaction of the licensing authority a prima facie case that the haulage work which he proposes to carry on cannot for some reason be done by other operators already engaged in carrying, whether by road or by rail.

Hiring. — A carrier desiring to secure licences for his own vehicles in lieu of hiring must show some special circumstances why hiring is unsuitable.

Measures taken by the Railways themselves to combat road competition.

Note. — The paragraphs hereafter are definetely confined to *new* measures taken by the Companies, but during the past year measures previously adopted have been widely developed and extended, e. g. evening excursions, holiday season tickets, collection and delivery by motor, agreed charges, etc.

Improvements in train services. — Extensive schemes for the acceleration of passenger trains have been carried out which bring up to 54 the number of long-distance express trains travelling at an

average speed of 60 miles an hour or over from start to stop.

New express goods trains have also been introduced and existing services extended and improved with the object of still further expediting the delivery of goods traffic. The fastest goods trains run at average speeds of 45 miles an hour and are composed of vehicles fitted with vacuum brakes.

Travel savings cards. — A travel savings scheme, formerly operating experimentally at a few selected stations, has been considerably extended.

The savings cards are obtainable at the stations and are provided with space for twenty sixpenny or ten one shilling stamps.

A fully stamped card represents a face value of ten shillings and may be presented at the railway booking office in full or part payment for any description of ticket, except, in certain cases, season tickets.

If the card (or cards) does not meet the cost of the railway ticket required, the deficiency is made good in cash, whilst a balance of stamps in the passenger's favour is refunded as change.

Mystery tours by railway. — A number of « mystery » tours have been arranged and have proved successful.

Excursions were advertised to an unknown destination, and ran from big centres to a local beauty spot, country or riverside. In addition diesel railcars, where available, were utilised for circular trips allowing an hour or more wait at several points en route, and descriptive literature was handed to each passenger at the starting point of the train.

It is proposed to develop this class of excursion.

Cartage facilities. — Considerable developments in connection with cartage facilities afforded by the British Railways in rural districts have taken place, and the number of country lorry services run by the Railway Companies referred to in the report for 1930 has been increased. A progressive policy has been adopted in the allocation of motor vehicles at stations in agricultural areas, thereby augmenting the services between farms and residences and the railway stations.

The Companies have been subjected to severe competition in the transport of grain, oil cake and packed manure from the ports. With the object of retaining present carryings and as an endeavour to recover traffic lost, a system of « delivered rates » has been inaugurated. These rates include delivery to consignees and are looked upon by traders as being a distinct advance in railway transport for this class of traffic. Although the rates have been in operation only a short period, experience shows that this forward policy has been fully justified and its extension to other important traffics hitherto only carried at « station to station » rates is indicated.

[621. 33 (.485)]

Electrification of the Swedish State Railways,

by Ivan ÖFVERHOLM,

Chief Engineer for Electrification, Royal Swedish State Railways.

At the end of 1933, the total length of the Swedish railways was 16 543 km. (10 280 miles), 7 427 km. (4 615 miles) of which belonged to the State and 9 116 km. (5 665 miles) to private companies.

The traffic over the State lines in the same year amounted to 35 606 000 train-km. (22 125 000 train-miles) and 959 138 000 axle-km. (595 992 000 axle-miles), giving an average of 5 018 train-miles and 135 174 axle-miles per mile of track and per annum.

The traffic over the private lines in the same period was 36 326 000 train-km. (22 572 300 train-miles) and 619 590 000 axle-km. (385 000 200 axle-miles), corresponding to 3 889 train-miles and 66 330 axle-miles per mile of track per annum, or about half the traffic on the State lines, calculated in axle-kilometers or axle-miles.

According to the decisions taken up to now by the Government 3 237 km. (2 011 miles) of the State lines will be electrified before the end of 1937, which corresponds to 43.6 % of the State system. The electrification of 2 135 km. (1 327 miles) was completed at the beginning of 1935.

The parts of the system to be electrified are those carrying the heaviest traffic, with the result that, using the 1933 published figures, 70 % of the train-miles and 79 % of the axle-miles will be operated electrically.

It is also proposed to electrify 1 233 km. (766 miles) of the secondary lines included in the State system, and if this is carried out, 60 % of the total State system with 82 % of the traffic in train-miles and 90 % of that expressed in axle-miles will be electrified (see fig. 1).

This would leave 40 % of the State system not electrified; this part of the system has very light traffic, only 18 % of the total train-miles and 10 % of the axle-miles.

Expressed in axle-miles per mile of track per annum, the traffic on the lines to be, or which is it proposed should be, electrified is on the average 50 % higher than the average volume of the traffic on the whole system; the traffic on the remaining lines is only one quarter of the total traffic, or one sixth of the traffic on the lines to be electrified.

The electrified lines of the State consumed 260 million kilowatt-hours in 1934. When the electrification programme is completed, the annual consumption will be 430 million kilowatt-hours, the maximum power required amounting to 100 000 kw.

If the whole of the railway system were electrified, the energy consumption would be about 830 million kilowatt-hours per annum, and the maximum power required 210 000 kw. The hydro-electric power resources of Sweden are estimated at 32 billion kilowatt-hours per annum and the maximum power at 6.5 million kilowatts. In 1934, only 6.05 bil-

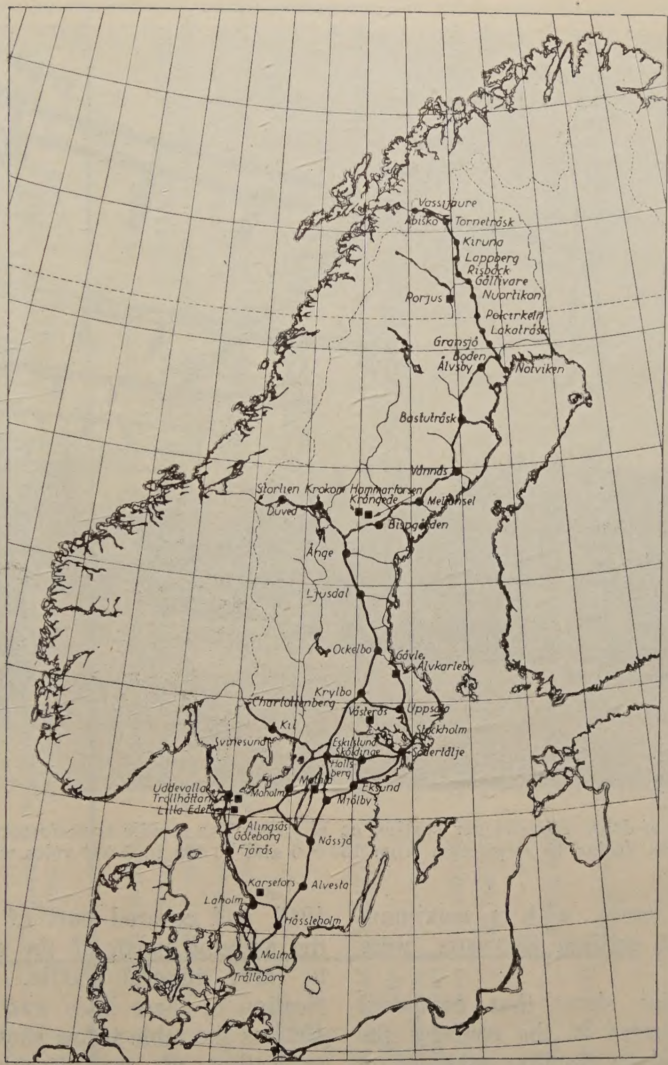

Fig. 1. — Map of Sweden showing the electrified lines, the lines being electrified, and the projected electrification of lines belonging to the State Railways.

LEGEND.

Position at the 1st January 1935.

▬▬▬ Lines electrified, in service or under construction:

In service: 1 102 km. (685 miles).

Under construction: 1 229 km. (764 miles).

- - - - - - Lines to be electrified (projected).

Total length of the State Railways at the end of 1934: 7 446 km. (4 627 miles).

■ Power stations.

●• Substations.

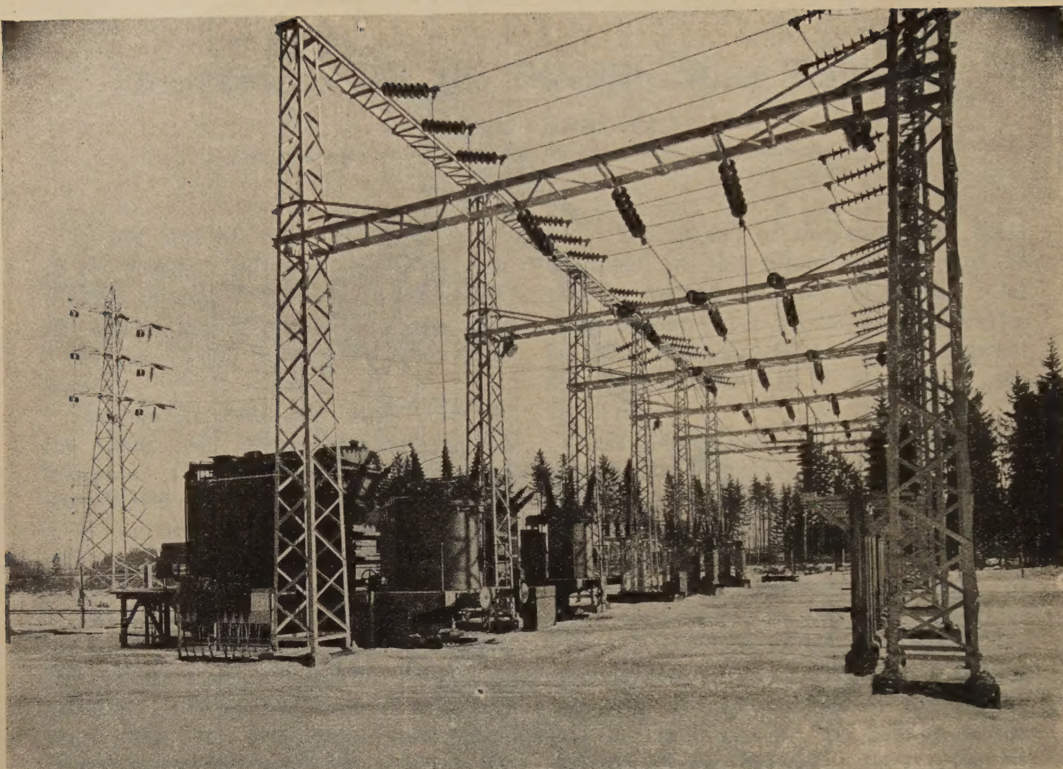

Fig. 2. — Out-of-doors transformer station at Krylbo. The mobile transformers and circuit breakers of Asea design to step down from 130 000 and 70 000 to 6 300 volts will be noticed.

lion kilowatt hours, with a maximum power of 1.42 million kilowatts, were used.

These figures show that compared with the resources of the country, the energy required for traction purposes on the whole of the Swedish railways is very small, being only 2.6 % expressed in kilowatt-hours and 3.2 % in kilowatts.

The electrification of the Swedish State Railways was begun in 1905 by a test length which remained in service till 1907. The first important electrification scheme was put into service in 1915, and covered part of the lines in the extreme north of the country, used to carry mineral traffic. The electrification of these lines was completed in 1923 as the table below shows. The electrification of the *Stockholm-Göteborg* line was completed in 1926. The electrification slowed down until 1931 when it was resumed at a markedly accelerated rate. On the average 50 km. (31 miles) of line were electrified monthly, and the work already authorised will be continued at this rate until the end of 1937.

The same table also shows that the electrification has been carried out in

Electrification of the Swedish State Railways.

Electrified lines.	« Mineral » lines.	Stockholm-Göteborg.	Stockholm-Malmö.	Stockholm-Ange.	Göteborg-Malmö.	Proposed electrification.	Total.
Years carried out	1910-1922	1923-1926	1931-1933	1933-1935	1934-1936	1935-1937	...
Length of electrified *lines* . . .	451 km. (*280.2 miles*)	459 km. (*285.2 miles*)	862 km. (*535.6 miles*)	617 km. (*384 miles*)	316 km. (*196.4 miles*)	532 km. (*330.6 miles*)	3 237 km. (*2011.4 miles*)
Length of electrified *track* . . .	599 km. (*372.2 miles*)	880 km. (*546.8 miles*)	1 624 km. (*1009.1 miles*)	935 km. (*581 miles*)	515 km. (*320 miles*)	759 km. (*471.6 miles*)	5 312 km. (*3300.7 miles*)
Number of electric locomotives .	67	64	105	80	43	42	401
Cost of electrification.							
Power distribution plant, crowns	28 540 000	19 630 000	28 500 000	20 900 000	11 800 000	14 030 000	123 400 000
Alterations to telegraph, telephone, lighting and signalling lines, and to the track and bridges . . . . crowns	1 380 000	10 230 000	13 200 000	10 900 000	5 630 000	7 200 000	48 540 000
Locomotives, etc.	21 160 000	14 740 000	21 800 000	17 700 000	9 720 000	8 640 000	93 760 000
Total in crowns . . .	51 080 000	44 600 000	63 500 000	49 500 000	27 150 000	29 870 000	265 700 000
Energy consumption, kw./h. per annum	95 000 000	75 000 000	125 000 000	70 000 000	35 000 000	30 000 000	430 000 000

The energy for the « mineral » lines is supplied as single-phase from a special power station.

The energy for the other lines is supplied as 50-cycle 3-phase 6 300-volt to substations equipped with converter sets.

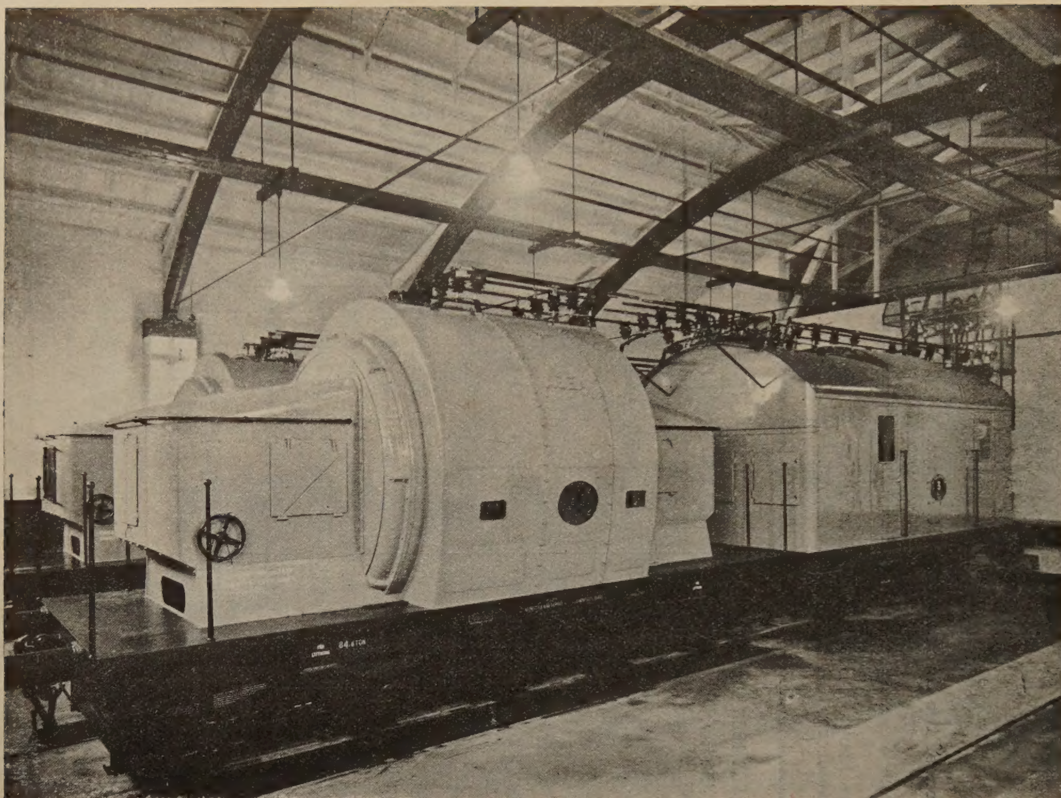

Fig. 3. — Interior of the Uppsala substation, and converter sets. The mobile Asea converters sets weigh 126 t. (124 Engl. tons) and are carried on 7 pairs of wheels, each pair carrying a load of 18 t. (17.7 Engl. tons) each.

six stages, and the total cost of the full programme will be 265.7 million crowns.

The system of electrification to be adopted has been investigated on several occasions by experts in the matter. Each time the single-phase system was found the best suited to Swedish conditions.

The energy for traction purposes on the mineral lines is supplied as 15-cycle single-phase current, special generators being provided for the purpose in the Porjus station : transformers step up the voltage to 80 000 volts. The energy is transmitted over special lines to the railway, thirteen substations, about 35 km. (21.7 miles) apart being provided along the 434 km. (270 miles) of track. The voltage is stepped down in these substations to 16 000 volts, the pressure of the contact line.

The energy required for traction purposes on the other lines is taken from the high-tension primary distribution network. The high-tension three-phase current is transformed in the substations, by rotary converters, into low-frequency 16 000-volt single-phase current fed to the contact line.

For convenience in transforming the current, the frequency adopted is 16 2/3 cycles. The average distance between the feeder points to the railway (or between substations) is 100 km. (62 miles) with a maximum of 150 km. (93 miles).

The first substations were fitted with fixed converters, 11 substations so equipped being in service.

The further 10 substations required for the present electrification programme will be equipped with mobile converters; similar sets will be used as spares for the substations fitted with fixed sets (fig. 3).

The new type of substation is merely a kind of garage. The mobile converter sets are of exactly the same power as the fixed sets. They consist of an alternating-current 6 300-volt 50-cycles synchronous motor and a single-phase 3 000-volt 16 2/3-cycle synchronous generator, each machine having its own exciter. To raise the voltage on the single-phase side from 3 000 to 16 000 volts, a transformer is used mounted on a wagon in the case of the mobile sets. On the single-phase side, the power supplied by the whole of the converter sets is 3 000 kVA in normal service and 6 000 kVA during peaks.

Figures 4 and 5 show the arrangement adopted for the overhead line. The carrying wire has a section of 50 mm^2 (0.0775 sq. inch) and the contact line 80 mm^2 (0.124 sq. inch), both made of copper, securely fastened together and each kept under constant tension by weights. The contact line is carried on poles built up of steel tubes which can move along the longitudinal centre line of the track. The sag of the contact line is thereby kept constant independently of temperature variations; it amounts to 6 cm. (2 3/8 inches) for the usual spacing of 60 m. (197 feet) between the poles. Experience has proved that a truly horizontal contact line was not satisfactory. The contact line is divided into lengths of 1 200 to 1 400 m. (3 900 to 4 600 feet), quite independent mechanically and insulated one from the other. A section cut-out switch is fitted between the sections and normally connects them together. At every fourth section a booster transformer is provided.

A return conductor is carried on the poles on the side of the track. It consists of copper cable of 130-mm^2 (0.2015 sq. inch) section. A high-tension conductor is mounted on the top of the poles; it carries 50-cycle high-tension current for the signals and other accessory purposes, the whole length of the track.

The telephone, telegraph, and signalling lines are cables laid in a ditch in the embankment. As a result of using a return conductor and booster transformers, there is no interference in these circuits.

The first electric locomotives of the Swedish State Railways, except the test locomotives purchased before 1910, were ordered for the extreme northern lines on which the traffic is mostly mineral. They were therefore designed for a very difficult service (very heavy goods trains) as the passenger service was relatively light.

On the other hand, the Stockholm-Göteborg line required locomotives for express trains, stopping passenger trains, local trains, goods trains, and for shunting. In order to investigate this problem, a Committee of experts was appointed. The Committee proposed 4 different types of locomotive. When the problem was examined further, however, it was found that one single type should be able to meet the various service conditions laid down, and ultimately a new

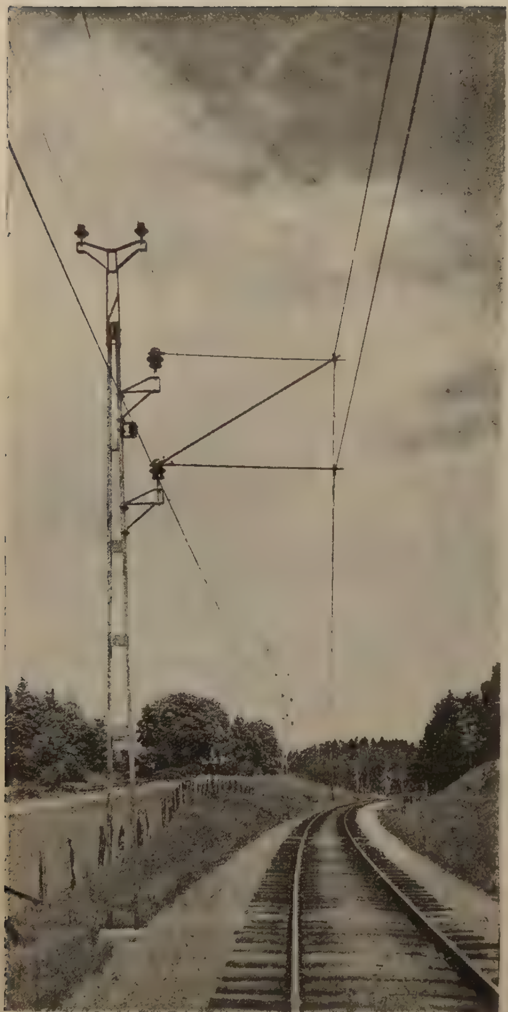

Fig. 4. — Single-track line. The contact wire and carrying wire, both copper of 80 and 50 mm² (0.124 and 0.0775 sq. inch) section are located above the centre line of the track. The return conductor will be noticed on the posts; it has a section of 130 mm² (0.1215 sq. inch). The lighting line at 10 000 volts 50 cycles will be noticed on the top of the poles, the two copper conductors each being 30 mm. (0.0465 sq. inch) section.

Fig. 5. — Section point with booster transformer and *Asea* equipment carried on the post (present arrangement).

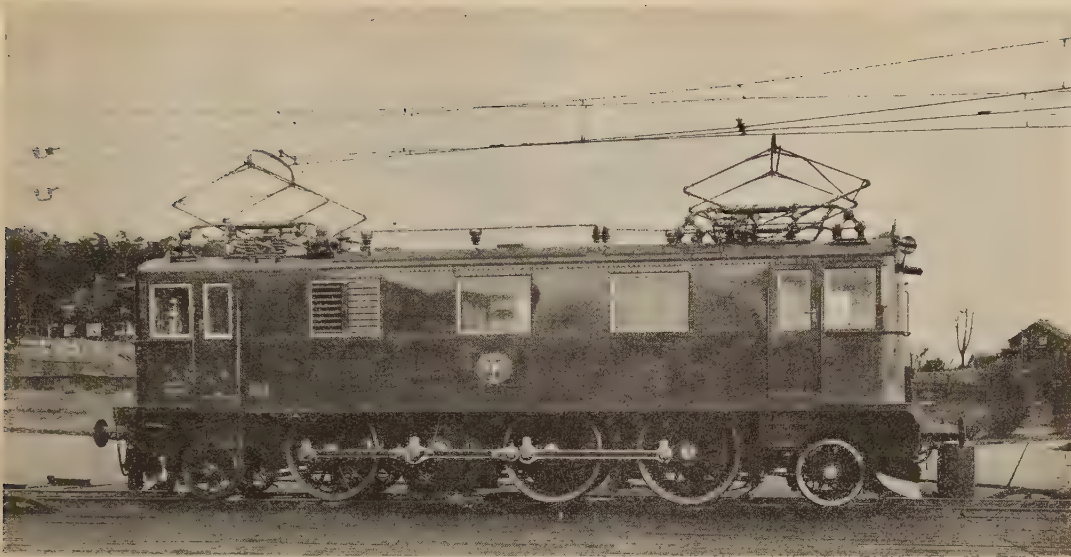

Fig. 6. — *Asea* type D locomotives.

Weight 80 t. (78.7 Engl. tons). Adhesive weight 51 t. (50.2 Engl. tons). Maximum tractive effort 17 t. (16.7 Engl. tons). 268 locomotives of this type are in service or under construction.

Fig. 7. — *Asea* type U*b* shunting locomotive.

Weight 48 t. (47.2 Engl. tons). Maximum tractive effort 16 t. (15.7 Engl. tons). 40 locomotives of this type are in service or under construction.

type of locomotive particularly suitable for the service in question was designed, the type D Asea locomotive, with three pairs of driving wheels and a carrying pair of at each end. This locomotive is used for all purposes at the present time (fig. 6). It has two motors which drive a jack shaft through gearing. The jack shaft is carried on the locomotive frame on a level with the driving axle centres which it drives through horizontal coupling rods. The locomotive weighs about 80 t. (78.7 Engl. tons) with 51 t. (50.2 Engl. tons) on the drivers.

In order to be able to use this locomotive in passenger and goods services, two sets of gearing have been provided. The locomotive, when working express trains, can haul a train of 550 t. (541 Engl. tons) at a maximum speed of 100 km. (62 miles) an hour, and in goods working, of 900 t. (886 Engl. tons) at a maximum speed of 75 km. (46.6 miles) an hour. The gearing can be changed in the shops in a few days.

Out of the 401 electric locomotives required for the electrification programme, 268 are of the D Asea type.

This type was, however, found unsuitable for shunting, especially when single-manned. For this reason, the type *Ub* Asea locomotive was designed with the same motors as the type D and 6 driving wheels (see fig. 7). 45 locomotives of this type will be provided.

The object of the electrification of the Swedish State Railways has been from the first to use water power for traction purposes. This object has, however, been more than achieved as the service has been improved and speeded up; the electrification has, moreover, enabled the State Railways to meet with greater success competition from other forms of transport, a matter of special importance at the present time.

[625 .14 (01]

Track laying for high speeds,

by Felice CORINI,

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FIRST NOTE.

I. — Introduction.

The ever increasing competition between the different forms of transport to attain very high speeds has brought the layout and construction of the track into the foreground in the case of land transport.

The problems involved in the layout may be considered as satisfactorily solved both for rail and road transport. The problem of the structure of the ordinary road has also received practical solutions meeting the very difficult requirements. The problems involved in the construction of railway permanent way, on the other hand, are still to a large extent unsolved.

The track today is much the same as when railways were first built. Much of the progress made has been due to changes in the dimensions of the different component parts and to improved materials. Thus, the first layer of ballast was about 10 cm. (4 inches) deep, whereas today the depth exceeds 45 cm. (18 inches); the gravel formerly used has been replaced by sharp chipped stone. The dimensions of the sleepers have not changed, but the spacing has been reduced, in some cases to less than 60 cm. (2 feet). The rails are sometimes made of special steel and the ever increasing weight now exceeds 55 kgr. per m. (110.9 lb. per yard) on lines carrying the heaviest traffic; the length has increased from 9 to 12 m. (29 1/2 to 39 feet), then to 18 m. (59 feet), and the most up to date lines have been relaid with 30-m. (98 1/2 ft.) rails. The rail fastenings have been improved, the rails now being fastened indirectly to the sleepers instead of directly.

In spite of all this, however, there are weak points in the track; the many joints hinder the introduction of the higher speeds the rolling stock is capable of.

The high-speed problem is not chiefly one of locomotive streamlining; it is essentially one of stability and comfort.

The abnormal movements of the vehicles, mainly due to the layout and structure of the track may compromise the stability of vehicles running at high speeds, and make such speeds unbearable for the passengers.

As we have already said, rational layouts and gradients which will meet modern requirements can be adopted. The joints, however, remain, and form one of the obstacles to high speeds. At each joint the stock receives shocks which cause vibrations and rolling, increasing in violence as the speeds are raised and joints become more frequent.

The continual technical progress in permanent way engineering will doubt-

less result in radical alterations in the track, possibly in the ballast and sleepers being replaced by concrete beds and spring supports. Such a change, of course, would take a long time to elaborate, design, and test. But the joint problem now appears ripe for a radical change.

The complete suppression of joints by welding as practised on tramways, where the paving protects the rails from changes in atmospheric temperature, by reducing the amount of variation, is not directly applicable to the present design of railway track.

The problem which can be solved promptly to-day is that of the maximum permissible gap at the joint and the corresponding maximum practical length of rail.

A few studies have been published in recent years on this question; the most complete are those of WATTMANN and BATICLE (see *Bibliography* at the end of this note).

These investigations have made clear how rails expand, the effect of the joints on such expansion, the slipping resistance of the rails on the sole plates, and the creeping resistance of the sleepers on the ballast.

The fundamental point of the question, namely how to ascertain the conditions under which the track gets out of line, has not been settled satisfactorily, neither theoretically nor practically, even in the case of straight track.

No attempt seems to have been made to solve the problem for curved track.

The fundamental defect in BATICLE's theoretical study is that be has taken the resistance of the track to transverse displacement as proportional to the displacement itself, as the result of applying a hypothesis which can be accepted when dealing with the vertical deformations of the track, to the study of the transverse deformation, in which case it is not acceptable (1).

The sliding resistance in a plane parallel to that of the track is primarily due to the frictional resistance between the sleepers and the ballast and between the first and second layer of ballast, and secondly to the compression resistance of the ballast transversely and longitudinally. The reason for this is that the volume of the ballast possibly subjected to compression and not to simple displacement may be said to be almost nil in the transverse direction and always very small in the longitudinal.

Consequently, the resistance to transverse sliding may be considered more correctly as constant and equal to the friction mentioned above.

The adoption of this new hypothesis leads to a differential equation of the elastic line entirely different from that which can be deduced from the former hypothesis. Premises such as, for example, those ALBENGA used so brilliantly when dealing with the problem of the lateral bending of piles driven into the ground, cannot be adopted when integrating it.

From the experimental point of view, the question cannot be said to have been disposed of. The tests made by RAAB (see *Bibliography*) were carried out without any organic plan and, whilst very interesting, did not give any results of general application.

The object of the present notes is to deal fully and systematically with the

(1) This hypothesis has been adopted in turn by other authors (see *Bibliography*).

problem of the expansion and deformation of rails, both theoretically and experimentally; theoretically by adopting the correct hypotheses mentioned above, and experimentally by following an organic plan such that the results of the test would be of general application.

This first note dealing with straight track will be followed by a second, devoted to curved track.

II. — Expansion of the rails and longitudinal sliding.

Let us consider a section of track between two joints and let $2l$ be its length.

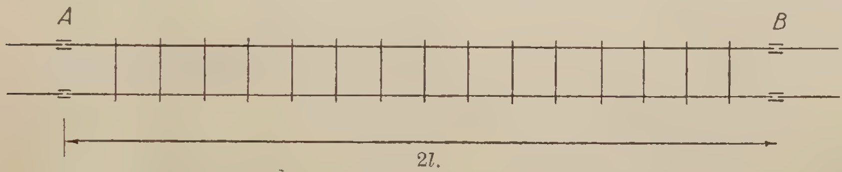

Fig. 1.

The rails are connected as follows :

1. The connection between the rail and fish-plates at the rail ends A and B, by means of bolts : the sliding between the rail and the fish-plate is opposed by the frictional resistance between the surfaces of the rail and fish-plates in contact, R_1, proportional to the normal pressure set up by the bolts;

2. The connection between the rail and the sleepers through the sole plate, by spikes. Sliding between the rail and sole plate is opposed by the frictional resistance proportional to the normal pressure set up by the spike.

Let r_1 be the frictional resistance for each fastening; the resistance per linear metre will be $\frac{r_1}{d}$, d being the distance between sleepers.

Two values of r_1 have to be considered: the value r'_1 when the rail is fastened directly, and r''_1 when the rail is fastened indirectly, whence $\frac{r'_1}{d}$ and $\frac{r''_1}{d}$ are the respective resistances per linear metre.

3. Connection between the sleepers and the plane represented by the upper surface of the first layer of ballast. The sliding resistance is due to the friction between the sleepers and the ballast, and in the ballast itself. Let $2\, r_2$ be this resistance per metre; it will be r_2 per rail.

When the rails are stressed longitudinally, sliding may take place between rail and sole plate if $\frac{r_1}{d} < r_2$, and between the sleepers and the first layer of ballast if $\frac{r_1}{d} > r_2$.

Let r be the greater of the two values $\frac{r^1}{d}$ and r_2, and let us see how the length of the rails changes when subjected to temperature variations.

In this preliminary examination let us assume that there is a gap between successive rails at the ends A and B, so that they never touch.

Let us also suppose the rail was laid at a temperature t_0 and let us examine the conditions at a temperature $t > t_0$ (fig. 2).

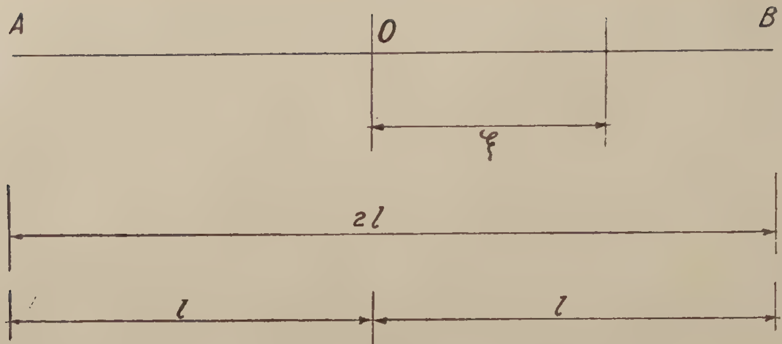

Fig. 2.

If the rail were not assembled in any way, the elongation per metre would be

$$\varepsilon = \alpha\,(t - t_0) \quad . \quad . \quad . \quad (1)$$

taking the coefficient of linear expansion of the steel $\alpha = 0.000012$.

This elongation can also be produced by an axial stress giving the unit stresses :

$$\sigma = E.\,\alpha\,(t - t_0) \quad . \quad . \quad . \quad (2)$$

in which E is the modulus of elasticity of the steel.

The thermic expansion corresponding to the increase in temperature $t - t_0$ corresponds to an elastic elongation due to an axial stress

$$F = S.\,\sigma = S.\,E.\,\alpha\,(t - t_0) \quad . \quad (3)$$

wherein S is the cross sectional area of the rail.

When the rail is laid in place, its behaviour can be studied by considering the two axial forces F and — F applied to the ends A and B, instead of the rise in temperature. Let us now consider the same rail connected up as mentioned above. The conditions are symmetrical relatively to the centre point O of the rail, which consequently can be taken as fixed in all cases.

Let O be the origin of the abscissæ OB and OA. Let us also consider a segment of abscissae . This segment is subjected to the following forces : to F, positive force passing through the centre of gravity (from O towards B); to R_1, negative force through the centre of gravity, and to the resultant of the distributed forces r per metre, applied with an eccentricity e equal to the distance between the centre of gravity and the lower edge of the rails.

Seeing that R_1 and r are reactions, sliding occurs in the direction OB when F exceeds the resultant of the reactions. No sliding occurs when F is equal to or less than the resultant of the said reactions.

If x be the distance of the section farthest from O in which there is no sliding, we can write :

$$F = R_1 + \int_x^l r,\, d\xi \quad . \quad . \quad (4)$$

in which the second term of the right-hand side represents the resultant of the successive reactions.

Using (3) and integrating, we get :

$$S\;E.\,\alpha\,(t - t_0) = R_1 + r\,(l - x)$$

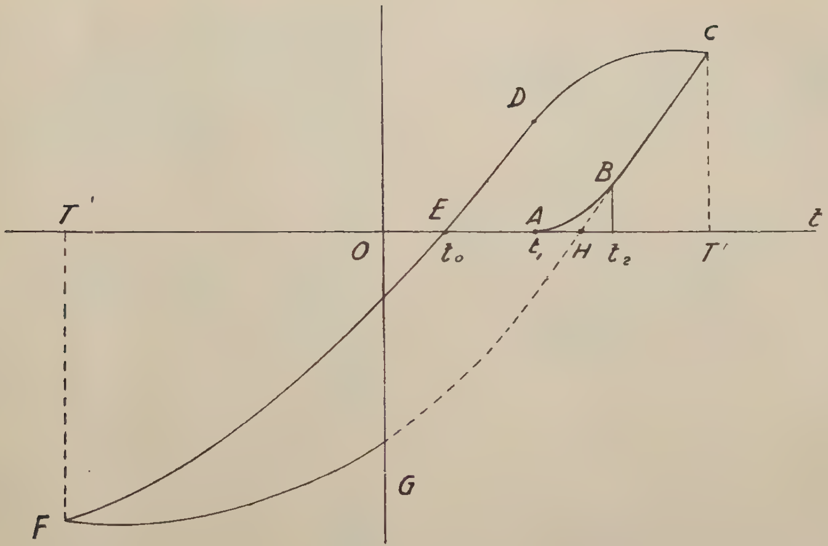

Fig. 3

whence

$$x = l - \frac{S.\,E.\,\alpha\,(t - t_0) - R_1}{r}. \qquad (5)$$

The displacement of a segment of abscissæ ξ is given by

$$\lambda = \frac{1}{ES} \int_x^\xi [F - R_1 - r\,(l - \xi)]\,(d\xi)$$

or

$$\lambda = \frac{1}{ES} [F\,(\xi - x) - R_1\,(\xi - x) - rl\,(\xi - x) + \frac{1}{2}\,r\,(\xi^2 - x^2)]$$

$$\lambda = [\alpha\,(t - t_0) - \frac{R_1}{ES} + \frac{r}{2\,ES}(\xi + x) - \frac{r}{ES}\,l]\,(\xi - x) \quad . \quad . \quad . \quad (6)$$

Formula (6) can be used when λ is positive or nil. When $\xi = x$, $\lambda = 0$ in conformity with equation (5).

The displacement of end B is found by making $\xi = l$ or

$$\lambda_B = [\alpha\,(t - t_0) - \frac{R_1}{ES} + \frac{r}{2\,ES}(l + x) - \frac{r}{ES}\,l]\,l - x) \quad . \quad . \quad . \quad . \quad (7)$$

Substituting for x its value as given by equation (5) we get

$$\lambda_B = \frac{ES\,\alpha^2 (t - t_0)^2}{2\,r} - \frac{R_1\,\alpha\,(t - t_0)}{r} + \frac{R_1^2}{r\,ES}$$

or

$$\lambda_B = \frac{1}{2\,ES\,r}\,[E\,\alpha\,S\,(t - t_0) - R_1]^2 \qquad (8)$$

a quadratic function of $(t - t_0)$: when

$x = 0$, we get for equation (7)

$$\lambda_B = [\alpha (t - t_0) - \frac{R_1}{ES} - \frac{r}{2\,ES}\, l]\, l \quad (9)$$

a linear function of $(t - t_0)$.

$$\lambda = 0, \text{ for } t_0 \leqslant t < t_1 \,;\, t_1 = \frac{R_1}{E\,S\,\alpha} + t_0.$$

λ increases according to a parabolic law from t_1 to t_2, t_2 having the value for which $x = 0$, that is to say :

$$x = l - \frac{S\,E\,\alpha\,(t_2 - t_0) - R_1}{r} = 0;$$

whence

$$t_2 - t_0 = \frac{lr + R_1}{S\,E\,\alpha}$$

λ increases lineally when $t > t_2$.

The considerations developed when we take $t > t_0$ can be extended to the case in which $t < t_0$. The force F becomes negative, but at the same time R_1 and r become positive because they are reactions. We find for x and λ the equations (5) and (7) in which $t - t_0$ is replaced by $t_0 - t$.

The above formulæ clearly show that there is no well defined correspondence between the temperature at a given instant and the distance a section lies from the point of origin. This distance depends upon the above conditions as a whole; *succeeding phenonema* therefore must be considered.

We can see this quickly by comparing the graphs of the formulæ (8) and (9).

When $t_0 \leqslant t \leqslant t_1$, $\lambda = 0$; when $t_1 \leqslant t \leqslant t_2$, λ increases according to (8) and we get the parabolic arc AB; when $t > t_2$, λ increases according to (9) and we have the straight line BC.

If the temperature falls, λ diminishes according to formula (8) wherein, by using $T - t$ instead of $t_0 - t$, we get the parabolic arc CD; when $t > t_3$, which cancels x in the contraction stage, we get the straight line DF.

If we again raise the temperature from $- T''$ to $+ T$, we get the parabolic arc FG with the straight line GHC. In brief, the λ in terms of t follows a cycle similar to the magnetic and elastic hysteresis cycle.

It will be appreciated readily enough that the same kind of relations between λ and t can be arrived at starting from other initial conditions. The group of hysteresis curves for a rail could be drawn down. All the curves of a group passing through a given point $(t_1\, \lambda)$ give the various initial conditions and the intermediate states from which we can start to reach the position under consideration.

III. — Deformation of the track in the laying plane.

Let us consider a section of track AB, $2l$ long, laid at a temperature t_0 and heated to a temperature t. One section CD, $2x_1 = L$ long, undergoes no displa-

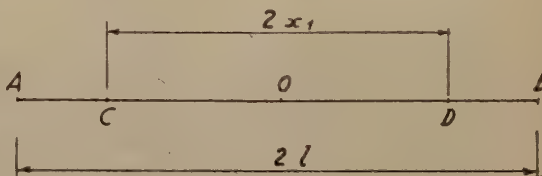

Fig. 4.

cement, x_1 being calculated from equation (5).

This section CD can be compared to a built up girder hinged at C and D and stressed by an axial force :

$$F_1 = 2\,F = 2\,E\,S\,\alpha\,(t - t_0)$$

and by a distributed force $2r_2$ per metre having the character of a reaction and not of a live force.

It should be noted that, unlike other authors, we consider the distributed force $2r_2 = r'_2$ as constant (equal to the friction already mentioned) and not as proportional to the lateral displacement. In a general study of the problem, F_1 can be considered as acting eccentrically, the eccentricity being δ.

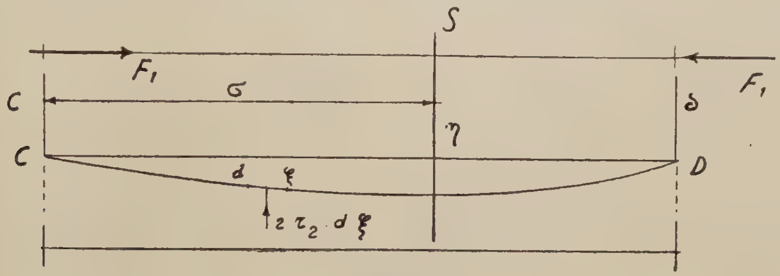

Fig. 5.

Taking C as the point of origin, a section S at a distance σ from C is acted upon by the force F_1 acting with a leverage $\delta + \eta$ and by the forces $r'_2 \ d \ \xi$ acting with a varying leverage $\sigma - \xi$. The moment of F_1 is given by F $(\delta + \eta)$ and the moment of the distributed forces by $- r'_2 \cdot \sigma \cdot (L -)\sigma$.

Let I be the moment of inertia of the track relatively to the vertical axis through the centre of gravity. We shall have $I = 2 \ A \left(\frac{s}{2}\right)^2$ if A be the area of the cross section of the rail, and s the gauge of the track.

The equation of the elastic curve is given by :

$$- EI \frac{d_2 \eta}{d \sigma^2} = F_1 (\delta + \eta) - r'_2 \sigma (L - \sigma) = M \quad . \ . \ . \ . \quad (10)$$

By deriving twice (see *Bibliography*) we get :

$$- EI \frac{d^4 \eta}{d\sigma^4} = F_1 \frac{d^2 \eta}{d \sigma^2} + 2 r'_2 = + \left(2 r'_2 - F_1 \frac{M}{EI}\right) \quad . \ . \ . \quad (10')$$

$$EI \frac{\delta^4 \eta}{d \sigma^4} = F_1 \frac{M}{EI} - 2 r'_2.$$

If we take :

$$z = - 2 r'_2 + F_1 \frac{M}{EI}, \ a^2 = \frac{F_1}{EI},$$

we get

$$\frac{d^2 z}{d \sigma^2} = - a^2 z. \quad . \ . \ . \quad (11)$$

The integral of (11) is

$$z = A \sin (a \sigma) + B \cos (a \sigma) \ . \quad (12)$$

or

$$- 2 r'_2 + \frac{F_1}{EI} \left\{ F_1 (\delta + \eta) - r'_2 \sigma (L - \sigma) \right\} = A \sin (a \sigma) + B \cos (a \sigma) \ . \quad (13)$$

whence :

$$F_1 \eta = [- F_1 \delta + r'_2 \sigma (L - \sigma)] + \frac{l}{a_2} [A \sin (a \sigma) + B \cos (a \sigma) + 2 r'_2)] \quad (14)$$

Let us calculate the constants so that we have :

for $\sigma = 0$ $\quad\quad \eta = 0$

for $\sigma = \frac{L}{2}$ $\quad\quad \frac{d\eta}{d\sigma} = 0$

We then have :

$$B = F_1 \delta a^2 - 2 r'_2 \quad \text{and}$$

$$A = (F_1 \delta a_2 - 2 r'_2) \operatorname{tg} \frac{a L}{2}$$

The equation of the elastic curve is therefore :

$$\eta = \left(-\frac{2 r'_2}{F_1 a^2} + \delta\right)\left(\operatorname{tg} \frac{a L}{2} \sin (a \sigma) + \cos (a \sigma) - l\right) + \frac{2 r'_2 \sigma (L - \sigma)}{2 F_1} \quad . \quad (15)$$

or again

$$\eta = \left(-\frac{2 r'_2}{F_1 a^2} + \delta\right)\left(\frac{\cos \frac{a L}{2} - (a \sigma)}{\cos \frac{a L}{2}} + 1\right) + \frac{2 r'_2 \sigma (L - \sigma)}{2 F_1}. \quad . \quad (16)$$

The deflection of the curve becomes

$$f = \left(-\frac{2 r'_2}{F_1 a^2} + \delta\right)\left(\frac{1}{\cos \frac{a L}{2}} + 1\right) + \frac{2 r'_2 L^2}{8 F_1}. \quad . \quad . \quad . \quad . \quad (17)$$

When $\delta = 0$, as is our case,

$$f_1 = \frac{-2 r'_2}{F_1 a^2}\left(\frac{1}{\cos \frac{a L}{2}} + 1\right) + \frac{2 r'^2 L^2}{8 F_1}. \quad . \quad . \quad . \quad . \quad . \quad (18)$$

When $\frac{aL}{2} = (2n + 1) \frac{\pi}{2}$, we have $\cos \frac{a L}{2} = 0$ and $f_1 = \infty$.

To prevent the profile of the line being dangerous

$$a L < \pi$$

and consequently

$$L < \frac{\pi}{a} = \pi \sqrt{\frac{E I}{F_1}} \quad . \quad (19)$$

The maximum value of L is that in which $f_1 = 0$, that is to say

$$\frac{1}{a_2}\left(\frac{1}{\cos \frac{a L}{2}} + 1\right) = \frac{L_2}{8}. \quad (19')$$

for the values of $a L < \pi$.

Obviously, when there is no lateral flexion between the sections CD, there is none between the sections AC and DB.

After having calculated the length L which satisfies formula (19) we can obtain from it

$$x_1 = \frac{L}{2}. \quad . \quad . \quad . \quad (20)$$

From equation (5) we obtain

$$l = \frac{L}{2} + \frac{S E \alpha (t - t_0) - R_1}{r} \quad (21)$$

and finally the maximum length of the rail

$$2l = L + \frac{2 S E \alpha (t - t_0) - 2 R_1}{r}. \quad (22)$$

The gap between the two consecutive rails will be $i = 2 \lambda_B$, λ_B being found from (7) in which x_1 is replaced by $\frac{L}{2}$.

IV. — Maximum length relatively to the maximum permissible gap.

So far the rails have been supposed to be free to expand, and this means gaps $2\,\lambda_B$ which generally speaking are out of the question for the values $2l$ satisfying the conditions above.

Let $2\,\delta$ be the maximum permissible gap. This is equivalent to saying that the expansion λ_B can only take place to the extent δ and that the two rails will have to transmit to each other a force Φ capable of cancelling the elongation $\lambda_B - \delta$. The value of this force Φ is given by

$$\Phi = \left(\frac{\lambda_B - \delta}{l - x}\right) 2\,\mathrm{E\,S}. \qquad (23)$$

We must now see that the length $2l$ of the rail meets the requirements of formulæ (19) and (19′) when applied to the case of the force Φ.

We should have :

$$2\,l < \pi \sqrt{\frac{\mathrm{E\,I}}{\Phi}}, \quad a_1 = \sqrt{\frac{\Phi}{\mathrm{E\,S}}}$$

and

$$\frac{1}{a_1{}^2}\left(\frac{1}{\cos\dfrac{a_1 \mathrm{L}}{2}} + 1\right) \leqslant \frac{(2\,l)_2}{8}$$

The value of $2l$ is obtained by successive approximations.

We have to ascertain the largest gap $2\,\delta$ compatible with good riding of the vehicles.

The maximum value of $2\,\delta$ should be such that the amount the wheels drop through gaps in the track lies within limits corresponding to possible vertical discontinuities.

Based on these discontinuities we ought to have :

$$h \geqslant \frac{\Delta^2}{2\,\mathrm{R}}$$

R being the radius of the wheels.

This gives

$$\Delta \leqslant \sqrt{2\,\mathrm{R}h}, \quad \Delta = 2\,\delta.$$

This maximum distance will correspond to the minimum temperatures.

The deformations could also be studied by no longer assuming the possibility of an unlimited displacement of the ends and by introducing, on the other hand, the hypothesis of a limited displacement $2\,\delta$ and the application of a force Φ increasing with the temperatures.

The formulæ used would be those found for $\lambda_B \leqslant \delta$ and those found by substituting for R_1, $\mathrm{R}_1 + \Phi$ with $\lambda_B > \delta$.

V. — Deformations in a vertical plane.

The deformations in the vertical plane may be grouped into :

a) those due to the track lifting; and

b) those due to the track sinking.

a) *Deformations through the track lifting.* — In the first case, the distributed force which resists the deformation consists of the weight of the track (metal parts and sleepers) and the frictional resistance of the sleepers and ballast through the intimate contact obtained by packing. This distributed force is independent of the deformation, and may be represented by r''_2.

Let I′ be the moment of inertia of a section of rails relatively to the horizontal axis passing through the centre of gravity. We have $\mathrm{I}' = 2i'$ if i' be the moment of inertia of one rail relatively to its horizontal axis through the centre of gravity.

Obviously $\mathrm{I}' < \mathrm{I}$ of chapter III (24).

The differential equation of the elastic curve is still equation (10) with I replaced by I′, and r''_2 substituted for r'_2.

If the track were not packed, $r''_2 < r'_2$ and, from formula (24), the rails

would be deformed in the vertical plane before being deformed in the horizontal.

If the track is very well packed, we can have $r''_2 > r'_2$ with opposite results.

In practice, the deformations always take place in the laying plane, because deformation is caused by the simultaneous action of temperature and locomotive running.

Whilst the transverse component of this action can deform the track horizontally, the vertical component prevents the track from lifting. This question will be investigated in a separate note.

b) *Vertical displacement by sinking.* — In this case, the continuous resistance proportional to the displacement can be represented by $B\eta$ and the differential equation of the elastic curve in place of formula (10′) is the following :

$$+ EI' \frac{d^4 \eta}{d\sigma^4} + F_1 \frac{d^2 \eta}{d\sigma^2} + B\eta = 0 \quad (25)$$

In this case η can be expressed by the Fourier series (1)

$$\eta = \sum_0^\infty a_m \sin\left(\frac{m\pi}{L}\sigma\right) \quad . \quad (26)$$

By substituting in (25) and resolving relatively to F_1 we get

$$F_1 = \frac{\left[EI' \sum\limits_0^\infty a_m \left(\frac{m\pi}{L}\right)^4 + B\Sigma' a_m\right] \sin\frac{m\pi}{L}x}{\sum\limits^\infty a_m \left(\frac{m\pi}{L}\right)^2 \left(\sin\frac{m\pi}{L}\sigma\right)} \quad (27)$$

Let us take

$a_0 = a_1 = a_{k-1} = .. a_{k+1} = .. a_n = 0 ; a_k \neq 0.$

and we get for F_1 :

$$F_1 = \frac{EI'\left(\frac{K\pi}{L}\right)^4 B}{\left(\frac{K\pi}{L}\right)^2} = \frac{EI' K^4 \pi^4 + B L^4}{K^2 \pi^2 L^2} \quad (28)$$

(1) See Albenga *(Bibliography)*.

or

$$F_1 = \frac{EI' K^4 \pi^4}{L^2} + \frac{B L^2}{K^2 \pi^2} \quad . \quad (29)$$

The value of K for which F_1 becomes a minimum is the whole number nearest to

$$K = \frac{1}{\pi} \sqrt[4]{\frac{B}{EI'}} \quad . \quad . \quad (30)$$

for which

$$F_1 = 2\sqrt{BEI'} \quad . \quad . \quad (31)$$

Whatever the length, there is no inflection if F_1 satisfies equation (31).

In view of the high value of B in the case of the track, the expression (31) always proves correct before the deformation in the laying plane shows itself.

VI. — Practices liable to result in maximum gaps at joints.

The considerations developed above show that the cause of the track getting out of alignment is the compressive stresses set up by loads on the rail ends. If a given value of F_1 can cause lateral bending through compression, the same absolute value acting in tension may give no trouble.

In order to make the distance between the rail joints as great as possible, the track should be laid and the welds made at a temperature t_s such that, if $t_{\min}$ is the minimum permissible temperature, the tensile stresses due to the difference in temperature $t_s - t_{\min}$, in conjunction with the stresses due to the loads, remain well within the breaking stress.

The distance between the joints will be calculated by the methods given in the previous chapters, the difference in temperature used being $t_{\max} - t_s$. In practice the rails would have to be heated beforehand by means of suitable electric equipment.

In the second part of this study, based on experiments, we give particulars of the experiments carried out to obtain the actual constants used in the theory expounded. The formulæ obtained will be applied to actual practical cases.

Finally we will give the results of a test which enables us to check the results of the theoretical investigation as a whole.

* * *

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* * *

SECOND NOTE.

I.

The previous note is a general study of the problem relating to the calculation of the longest possible rail length by ascertaining :

the expansion of the rail and the corresponding longitudinal sliding;

the deformation of the track in the laying plane;

the length of rail in relation to the greatest permissible gap;

the deformations in a vertical plane;

and finally the various factors tending to make the distance between the rail joints a maximum.

One of the first conclusions of a practical order drawn from the above study was the value of *preheating the rails beforehand* by a suitable electrical process so that the rails under variations of atmospheric temperature would be subjected mainly to tensile rather than to compression stresses.

Before other practical conclusions could be drawn, the values of the sliding resistances of the track on the ballast, in the longitudinal and transverse directions, and the sliding resistances of the rails on the sole plates, both when fastened directly and indirectly, had to be determined.

The formulæ found in the first note can only be used when the values of these resistances are known.

II.

First of all it should be noted that a long series of experiments are necessary to ascertain these resistances in the different conditions of the track met with in practice.

The general solution of the problem we are dealing with only requires, however, a knowledge of the order of magnitude of the abovementioned resis-

tances. For this reason we carried out only a limited number of tests, which are sufficient to make clear the relative importance of the said resistances [1].

In the third note will be given particulars of the above mentioned tests, carried out with the assistance of Professor Edmondo CASATI, with instruments belonging to the Laboratory of Applied Mechanics of the Higher Engineering School, Genoa.

The results may be summarised as follows :

A. Sliding resistance between the rails and supports, with direct fastening for each pair of fastenings : 3 300 kgr. (7 275 lb.); whence the resistance r for each direct fastening was 1 650 kgr. (3 637.5 lb.).

Sliding resistance between rails and supports directly fastened

$\frac{r'_1}{d} = \frac{1\,650}{0.65} = 2\,538$ kgr. *per metre* or 705 lb. *per foot* of track, (0.65 m. = 2 ft. 1 5/8 in. being the sleeper spacing.

Sliding resistance between rails and supports directly fastened, *per metre of track* : 5 076 kgr. $= \frac{2\,r'_1}{d}$.

B. Sliding resistance $2r''_1$ between rails and supports with indirect fastening, per pair of fastenings : 6 600 kgr. (14 552 lb.); whence the resistance r'' for each indirect fastening = 3 300 kgr. or 7 275 lb.

Sliding resistance between rails and supports with indirect fastenings $\frac{2\,r''_1}{d}$ = 5 076 kgr. *per metre* or 3 410 lb. *per foot of rail.*

Sliding resistance between rails and supports with indirect fastening $\frac{2\,r''_1}{d}$ = 10 152 kgr. per metre or 6 820 lb. per foot of track.

C. Longitudinal sliding resistance on the first layer of ballast $2r_2 = 613$ kgr. per metre (412 lb. per foot) of track.

D. Transverse sliding resistance of the track on the first layer of ballast $2r'_2$ = 257 kgr. per metre (173 lb. per foot) of track.

A fundamental observation can be deduced at once from the results of this test.

The longitudinal sliding resistance between track and ballast is appreciably lower than that between rails and supports. When direct fastenings are used the ratio of these resistances is about $\frac{6}{50}$ and with indirect fastenings $\frac{6}{100}$.

The deduction to be drawn therefrom is that the *deformations of the rails produce sliding of the whole track in the laying plane, whereas there is no sliding between the rails and the supports.*

The second conclusion of a practical order is :

If advantage is to taken, to the benefit of the stability of the track, of the high sliding resistance between rails and sole plates especially with indirect fastenings, the sleepers should be anchored to the ground.

The fundamental rule to be observed when building new track for high speeds is to heat the rails before laying them and to anchor the sleepers.

---

(1) A large number of systematic tests have been carried out on the Italian State Railways, at the Pontasieve depot, from which the sliding resistances between rails and sole plates have been calculated, and the results will be published by the Engineering Department.

III.

We will now determine the longest rail that can be used in the two following cases :

a) Use of the standard type of track and laying the rails after preheating them.

b) Use of track with anchored sleepers and laying the rails after preheating them.

In both cases the Italian State Railways' F. S. 46[3] track with sleepers spaced 65 cm. (2 ft. 1 5/8 in.) apart is used. In this case we have :

Cross sectional area of a rail . . . . $S = 59.26$ cm².
Modulus of elasticity . . . . $E = 2 \times 10^6$ kgr. per cm².
Coefficient of expansion . . . . $\alpha = 12 \times 10^{-6}$.

Maximum length of rails in ordinary track and rails heated before being laid.

As we saw in Note I, two conditions have to be taken into account when calculating the maximum length.

The first is that the length $2\,x = L$ of the centre part of the rail which does not lengthen, satisfies the equations (19) and (19′), i.e. is such that it is not deformed in the laying plane by the load on the end. The second is that the total length of the rails satisfies the equations (19_1) and $(19'_1)$ for an end load corresponding to the transmitted force between two consecutive rails for the limited gap at the joint.

Let us adopt this second condition : we will see that in the case of non-anchored sleepers it is much more restrictive than the first. The limits of temperature variation between which the stability of the track has to be guaranteed are defined by the extreme temperatures — 25° C. and + 55° C. (— 13° F. and + 131° F.).

We will begin by finding what is to be the laying temperature so that at the lowest temperature the gap shall lie between predetermined limits, and that the maximum tensile stress to which the rails may be subjected shall also be within predetermined limits, the gap when the rails are laid being taken as nil. We shall see if this hypothesis can be altered usefully.

The advantage of laying the rails with the ends touching is that they can be planed more easily in place to rectify any difference in height.

The maximum gap between rails is fixed between the limits explained in Note I.

For a maximum distance $2d$ of 0.5 centimetre, the maximum distance the wheels jump would be $h = \frac{d^2}{D}$ and when $D = 100$ cm., $h = 0.000625$ cm. or 6 thousands of a millimetre which would appear to be more than bearable. In any way, the correctness of this hypothesis has been proved more or less by experiments including the taking of diagrams of abnormal movements.

The maximum tensile stress that may be set up in the rail by temperature changes can be calculated by the following criterion.

The breaking stress of rail steel in the Italian State Railways' specification is 7 200 kgr. per cm² (45.7 Engl. tons per sq. inch.). With a factor of safety of 3.5, the safe stress as regards stability can be taken as 2 000 kgr. per cm² (12.7 tons per sq. inch.). If an allowance of 1 000 kgr. per cm² (6.35 tons per sq. inch) be made for the elastic stresses,

the maximum stress due to temperature may be limited to 1 000 kgr. per cm².

As the cross sectional area of a rail is 59.26 cm² the allowable tensile stress is :

F = 1 000 kgr./cm² × 59.26 cm² = 59 260 kgr. (58.3 tons). The temperature range is

$$\sigma = E \, . \, \varepsilon = E\alpha\,(t - t_o) \quad . \quad (1)$$

or

$$t_1 - t_o = \frac{\sigma}{E\alpha} = \frac{1\ 000}{24} = 41^\circ \ (2)$$

whence

$$t = t_o + 41^\circ \quad . \quad . \quad . \quad (3)$$

Making $t_0 = -25^\circ$

we get

$$t_1 = 16^0 \quad . \quad . \quad . \quad . \quad (4)$$

which means that the greatest gap between the rails should be found at + 16° C. (60.8° F.).

The laying temperature t_m and the rail length $2l$ are calculated so as to satisfy equation (9), $\lambda_B = 0.25$ cm. (0.0984 inch.) and equation (19), taking $x = 0$.

We will make sure that this hypothesis does correspond to the actual conditions of the track, as given above.

Formula 9 becomes :

$$\lambda = \left[\alpha\,(t_m - t_1) - \frac{R_1}{ES} - \frac{r}{2\,ES} . \, l\right] l = 0.25 \text{ cm.} = 0{,}0984 \text{ inch.} \quad . \quad . \quad (5)$$

in which R_1 is the sliding resistance between fish plates and rails taken as 10 000 kgr. and r the longitudinal sliding resistance between track and ballast for one centimetre length of *rail*.

With concrete values, equation 5 becomes :

$$0.25 = \left[12.10^{-6}\,(t_m - 16) - \frac{10\ 000}{2 \times 10^6 \times 59.26} - \frac{3.06}{2 \times 2 \times 10^6 \times 59.26} \times l\right] \times l . \quad (6)$$

Instead of considering the system of this equation and equations 19_1, let us make an investigation by successive approximations. Taking $2l = 10\ 800$ cm. (354.3 feet), t_m in equation (6) can be calculated. We find

$$250\ 000 = 64\ 800\,(t_m - 16) - 445\ 200 - 349\ 200$$

$$t_m - 16 = \frac{1\ 045 \times 100}{64\ 800} = 16$$

$$t_m = 32^0 \text{ C} = 89.6^0 \text{ F.}$$

Now let us see if the track of 108 m. (354.3 feet) lengths laid at 32° C. (89.6 F.) with the ends of the rail just touching when heated to 55° C. (131° F.) is under stable conditions.

As regards unit stresses we can be certain they will not exceed the 1 000 kgr. (6.35 Engl. tons per sq. in.) as the temperature rise is only 23° C. (41° F.), whereas the maximum stress would occur with a difference of 41° C. (73.8° F.), if there were no lateral bending due to end loads.

We can say therefore that the stress will be about 576 kgr./cm² (3.65 Engl. tons per sq. inch.).

We now have to see if there is any likelihood of the track being deformed in the laying plane.

If the rail ends were free to move, the longitudinal displacement would be, again supposing $X = 0$.

$$\lambda_B = \left[\alpha(t_{max} - t_m) - \frac{R_1}{ES} - \frac{r}{2ES}\, l\right] l \quad (7)$$

$$\lambda_B = \left[12 \times (55-32) - \frac{10\,000}{2 \times 59.26} - \frac{3.06}{2 \times 2 \times 59.26} \times 5\,400\right] \times 5\,400 \times 10^{-6} = 0{,}6\,912 \text{ cm.} = 0.272 \text{ inch.}$$

As no such expansion can take place, at the ends of the *track* there appear two forces Φ given by (20_A) :

$$\Phi = \frac{\lambda_B}{l} . 2ES = \frac{0.6\,912}{5\,400} \times 2 \times 2 - 10^6 \times 59.26 = 30192 \text{ kgr.} \quad . \quad . \quad (8)$$

For (19_1) we must have

$$2\,l < \pi \sqrt{\frac{EI}{\Phi}} \quad . \quad . \quad . \quad (9)$$

wherein

$$I = 2\,S\left(\frac{s}{2}\right)^2 = 624\,000 \text{ cm}^4. \quad (10)$$

We then find

$$\pi \, . \sqrt{\frac{EI}{\Phi}} = 16\,956 \text{ cm.} = 554.5 \text{ feet.} \; (11)$$

As $2l = 10\,800$ cm. $= 354.3$ feet, equation 9 is satisfied.

Let as now see if equation (19′) is satisfied :

$$\frac{1}{a_1{}^2}\left(\frac{1}{\dfrac{\cos a_1\,(2\,l)}{2}} + 1\right) > \frac{(2\,l)^2}{8} \quad (12)$$

wherein :

$$a_1 = \sqrt{\frac{\Phi}{EI}} = \frac{1}{5\,386}.$$

We then get :

$$\frac{1}{a_1{}^2} \times \left(\frac{1}{\dfrac{\cos a_1\,(2l)}{2}} + 1\right) = 3 \times (5\,386)^2 \; \frac{(2\,l)^2}{8} = \frac{4}{8}(5\,400)^2.$$

and consequently equation 12 is satisfied.

We still have to check the hypothesis that $x = 0$, i.e. that there is no portion of the rail which does not expand due to the assumed differences in temperature.

All that is needed for this is to use formula 5 of the first note :

$$x = l - \frac{S\,E\,\alpha\,(t - t_o) - R_1}{r}$$

By using the relative values either for the range + 32 to — 25° C. or + 32 to + 55° C. negative values of x are obtained.

As r and R_1 are reactions, the interpretation $x = 0$ naturally follows.

The conclusion we come to is that for the ordinary type of track, i.e. without the sleepers being anchored, *rails 108 m. (354.3 feet) long* [obtained by welding together 18-m. (59 ft. 5/8 in.) rails] *can be used if they are laid at a temperature of 32° C. (89.6° F.) with the ends in contact and by making the bolt holes in the rails and fish plates and the bolts of*

such diameter as will allow each end a maximum displacement of 0.25 cm. (0.0984 inch.). Under these conditions the track is stable for temperature variations between — 25° and + 55° C. (— 13° F. + 131° F.). The most severe track conditions are at — 25° (— 13° F.) at which temperature the rails are subjected to a positive unit tensile stress of 1 000 kgr. per cm² (6.35 Engl. tons per sq. inch.).

Rail steel should therefore have a breaking strength of not less than 7 000 kgr. per cm² (44.4 Engl. tons = 99 600 lb. per sq. inch.).

IV.

Now let us study the conditions of the new type of track with anchored sleepers.

First of all we must see how this anchoring can be provided.

The simplest methods are based on the principle of the x hooks, consisting of latticed elements mainly stressed in shear so that the pull on them is reduced to a minimum.

In the case of railway lines the existence of the first layer of ballast prevents this principle being applied.

Consequently the anchoring of the sleepers will only be made possible by tying them together longitudinally with flat steel bars, nailed to the ends, and by connecting them to concrete posts embedded in the ground.

The distance between the posts must be less than 20 times the rail height to prevent deformation in the vertical plane.

With such anchoring the question of the track sliding on the ballast need no longer be considered, but only possible slip between the rails and supports.

Furthermore, the transverse sliding resistance depends upon the reaction between the soil and the posts embedded in it; in this case this resistance can be considered as proportional to the displacement .

The conclusions deduced from the study of point (b) of § IV in the first Note are therefore applicable to this case.

This is equivalent to saying that, *whatever the rail length,* there is no deformation in the horizontal plane provided that the axial force F_1 satisfies the condition :

$$F_1 < 2\sqrt{B E I}.$$

The problem considered from the constructional point of view can be brought down to the following :

We have seen that in order to keep the tensile stress in the rails at — 25° C. under 1 000 kgr. per cm², the rail temperature, when no further contraction is possible, should be 16° C.

When continuous rails without joints are used they should be laid at this temperature.

For a temperature rise up to 55° C. an axial force F_1 must be presumed, such that

$$F_1 = 2 S \sigma = 2 S E \xi = 2 S E \alpha (t_{max} - t_m).$$

For the Italian State Railways' track when

$$t_{max} = 55^0 \qquad t_m = 16^0$$

we find

$$F_1 = 112\,320 \text{ kgr.}$$

The unit compressive stress will certainly be below 1 000 kgr. cm².

To prevent deformation in the horizontal plane, a type of anchorage is required such as will satisfy formula (13), i.e. such that the coefficient of proportionality which gives the lateral sliding

resistance per unit of length, in terms of the displacement shall be given by

$$B \geqslant \frac{\left(\frac{F_1}{2}\right)^2}{EI} = \frac{3\,025 \times 10^6}{2 \times 10^6 \times 620\,000}$$

B = 0.0016 kgr. per centimetre of track and per centimetre of displacement.

With a safety factor of 10, we get B = 0.016 kgr. per centimetre of track and per centimetre of displacement, or 1.6 kgr. per metre. This coefficient is small and readily obtained in practice even in ground of limited resistance by using concrete posts of limited side area, spaced as indicated above.

The conclusion is that if the sleepers are anchored and the rails are laid after preheating them the correct amount, an unlimited number of rails can be welded together and the joints done away with.

The above conclusions, which we consider of the greatest importance in connection with very high speeds, have been confirmed by many carefully carried out tests.

* * *

THIRD NOTE.

This Note gives the results of tests carried out to find the constants introduced in the second Note. These tests were carried out at the Genoa Higher School of Engineering, under Professor Edmondo CASATI.

The objects of these tests were :

a) To ascertain the resistance offered by the ballast to the *longitudinal sliding of the track* as a whole, i.e. sleepers, rails, and fastenings. (resistance given by $2r_2 = r'_2$ in the first Note).

b) To arrive at the resistance offered by the ballast to the *transverse sliding* of the track again considered as a whole (resistance r'_2 in the first Note).

c) To find the sliding resistance between the rails and sleepers when direct fastening is used (resistance r'_1 in the first Note).

d) To find the sliding resistance between the rails and sleepers when indirect fastening is used (resistance r''_1 in the first Note).

Tests a) *and* b).

a) A 2.25-m. (7 ft. 4 1/2 in.) length of Italian State 46^3 rails on four sleepers was laid in one of the courtyards of the School. The ballast of usual size was broken stone from the marble quarries as used on the lines of the Genoa division.

The first layer was 40 cm. (16 inches) thick; the second, the full depth of the sleepers. Then ends of the sleepers were covered with ballast to a depth of 12 cm. (4 3/4 inches).

The ballast was hand packed by trained men following the practice of the State Railways.

A capstan held down in the soil by Fioroni patented anchoring latticed elements was connected to a spring dynamometer reading a maximum pull of 10 000 kgr. (22 040 lb.) connected in turn by wire rope to the first sleeper (see photo 1).

When using the capstan, the initial longitudinal slip of the track occurred

Photo 1.

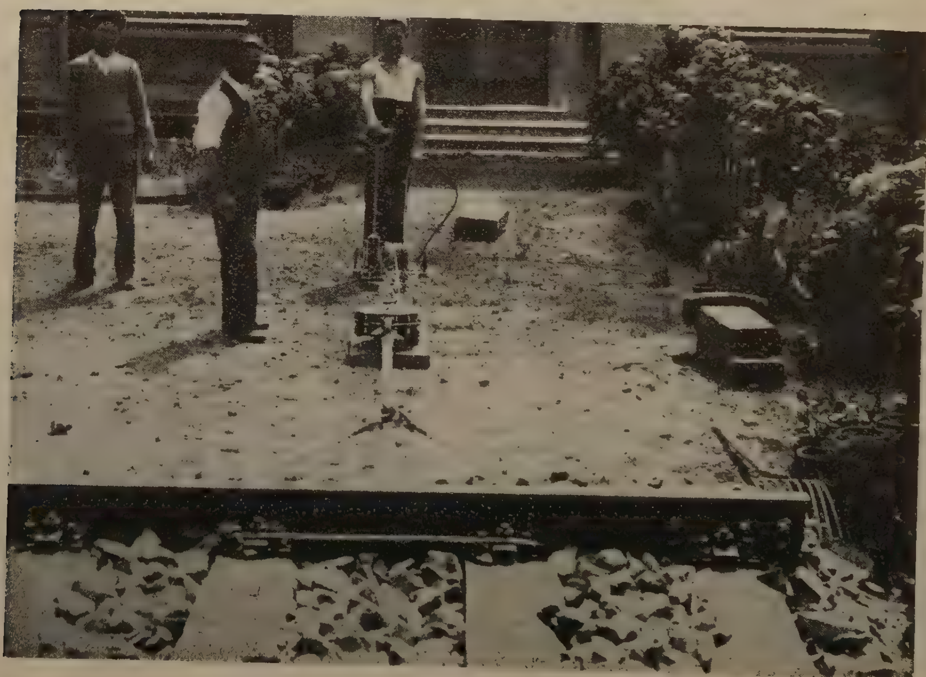


Photo 2.

with a pull of 1 380 kgr. (3 042 lb.). The pull was checked by an extensometer in the chain between the capstan and the dynamometer.

The test was repeated three times, the readings being :

1st test . . .	1 380 kgr.	(3 042 lb.).
2nd test . . .	1 360 kgr.	(2 998 lb.).
3rd test . . .	1 400 kgr.	(3 086 lb.).

The longitudinal slipping resistance of the track with 46^3 rails, for the ballast described, can be taken as

$$2\ r_2 = r'_2 = \frac{1\ 380 \text{ kgr.}}{2.25 \text{ m.}} = 613 \text{ kgr. per m. (411 lb per foot).}$$

As the weights of materials placed in the ballast are :

Broken stone : 2 000 kgr. × (2.60 × 0.14 × 0.32) × 4 . . .	=	932 kgr.
Rails : 46.3 kgr. × 2 × 2.25	=	205 »
Sleepers : 80 kgr. × 4	=	320 »
Fastenings : 18 kgr. × 4	=	72 »
Total . . .		1 529 kgr.

the average coefficient of friction between the sleepers and ballast and between the first and second layers of ballast is given by

$$f_1 = \frac{1\ 380}{1\ 529} = 0.90 \text{ approx.}$$

b) To ascertain the lateral sliding resistance, the same length of track and equipment as for tests (*a*) were used.

The connection to the capstan was altered, of course, so as to get a transverse pull, i.e. at right angles to the centre line of the track (see photo 3).

Sliding started at a pull of 580 kgr. (1 279 lb.). The test was repeated three times with the same result.

The transverse sliding resistance of the track on the ballast has therefore been taken as being

$$r''_2 = \frac{580}{2.25} = 257 \text{ kgr. per linear metre}$$

or 173 lb. per foot of track.

To ascertain the coefficient of friction, in this case almost solely between sleepers and ballast, the weights to be taken into consideration are :

Rails, sleepers, fastenings	=	600 kgr.
Broken stone (at ends) { 2 000 kgr. × (0.26 × 0.14 × 0.10) × 4 ; 2 000 kgr. × (0.26 × 0.50 × 0.25) × 4 }	=	176 »
		776 kgr.

We get therefore

$$f_2 = \frac{580}{776} = 0.74.$$

By varying the length of track tested, different enough values would have been obtained. As explained in the second note, the object of these tests was to ascertain the order of magnitude of the resistances in question. This is why the tests were limited to those made with the section of track mentioned.

Test c).

To find the sliding resistance between rails and sole plates using indirect fastening, two sections of 46^3 rail were laid with the proper sole plates, the bolts being tightened up fully and the standard Italian fish plates being fitted.

The sole plates were fitted with the top edge of the plate (with the sections arranged vertically) extending about 2 cm. ,25/32 inch) beyond the end of the

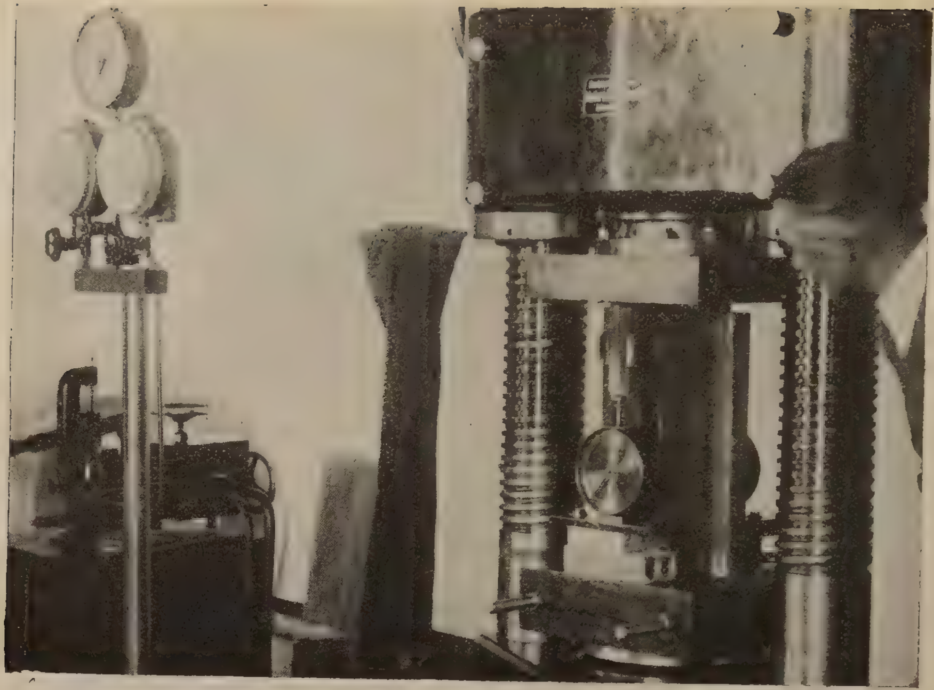


Photo 3.

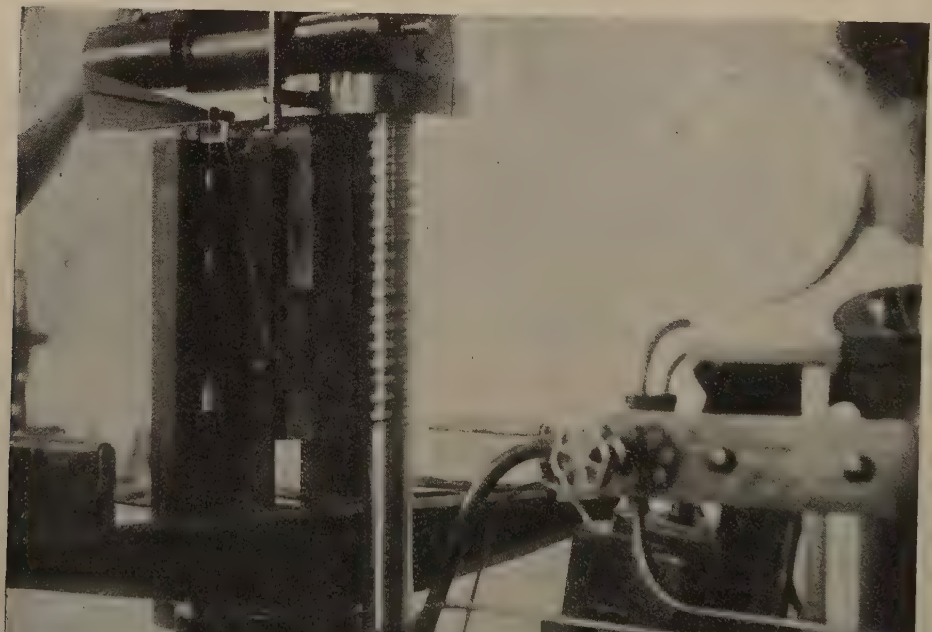


Photo 4.

rail. The two sections, with the respective sole plates facing one another, were placed in the jaws of the 500-ton Mohr and Federhaff testing machine of the building Materials Testing Office.

This arrangement ensured the forces tending to cause sliding to be centred. The relative sliding was measured by an ordinary Salmoiraghi flexometer with which displacements of one tenth of a millimetre can be read directly (see photo 3).

The tests showed that sliding began under a load of 6 600 kgr. (14 550 lb.).

As the same result was obtained when the test was repeated, the effort tending to cause sliding between the rail and its sole plate with indirect fastening can be taken as :

$$r''_1 = \frac{6\ 600}{2} = 3\ 300 \text{ kgr. } (7\ 275 \text{ lb.}).$$

Test d).

The sliding resistance between rail and sole plate with direct fastening was found in the same way. In this case the two sections of rail were laid on two sections of sleepers placed as longitudinal supports. The top of the sleepers projected about 2 cm. (25/32 inch) beyond the end of the section of rail. The forces acting were also centred by making the experiments with a pair of rail sections arranged symmetrically on a vertical plane. The test was carried out on the 60-ton A 1 Amsler machine in the laboratory in question.

The relative movements were read by means of a Griot flexometer (see photo 4).

Sliding was found to start at the following loads :

1st test . . .	3 400 kgr.	(7 495 lb.).
2nd test . . .	3 200 kgr.	(7 055 lb.).
Average . .	3 300 kgr.	(7 275 lb.).

From this the sliding resistance between rail and sole plate with direct fastening is :

$$r'_1 = \frac{3\ 300}{2} = 1\ 650 \text{ kgr. } (3\ 637.5 \text{ lb.}).$$

These tests show that the sliding resistance of the whole superstructure on the ballast is notably lower than the sliding resistance between rail and sole plate, whether with direct or indirect fastening. Consequently, all deformations of the track through various causes, especially variations in temperature, are always caused by the whole superstructure sliding on the first layer of ballast.

In order to take advantage of the high sliding resistance between rails and sole plates, the sleepers must be anchored to the ground.

[313 : 385 & 625. 2]

The time factor in railway economics and statistics,

by Dr.-Ing. Fritz LANDSBERG, Reichsbahnoberrat, i. R.

I. — Economic principles.

In all industrial undertakings the question of costs can be reduced to the following equation :

Total costs =
Expenditure on *wages* +
Expenditure on *materials* +
Capital charges (for the preservation and renewal of the assets) +
Miscellaneous charges (e. g. taxes, royalties, social charges, etc.).

The cost, i.e. the expenditure side of the production properly speaking, is the basis of all financial measures, especially those in which the receipts accruing from the products are taken into account. The equation also provides — as as whole and in its parts — the foundation on which the budget is prepared and checked, and in many cases the means of investigating the economy of the working.

So far as this article is concerned, in studying the question we must limit ourselves to deriving from this equation the *absolute* time factor, i.e. independent of the technical and financial management and its effects. This obviously means dealing with the expenditure per unit of production or work (unit cost).

The fundamental equation is valid for the total cost in a given period; it is also applicable to the total cost of a single unit. If the products are the same in kind, the unit cost can be ascertained from the ratio of the expenditure over a period to the number of units produced in that period.

In the opposite case, the cost of certain industrial products or groups of products can be found by bringing together the costs of production and dividing them by the number of units produced.

In each case, the following equation is obtained :

$$\text{Cost of the unit} = \frac{\text{Wages}}{\text{Number of units produced}} + \frac{\text{Cost of materials}}{\text{Number of units produced}} + \frac{\text{Miscellaneous charges}}{\text{Number of units produced}} + \frac{\text{Capital charges}}{\text{Number of units produced}}$$

The first two factors depend upon the industrial and commercial conditions, such as rates of pay, organisation of work, standard of equipment, kind of materials and how used, recovered waste products, etc. These elements into which the time factor also enters, whether industrial or « relative », influence the relation between cost of wages and materials, and the quantity produced. The numerator and denominator vary together according to laws depending on the particular nature of the production and the method of working.

The third factor depends upon administrative regulations and legal requirements.

The numerator of the last factor has a fixed value which only changes over long periods by increases or reductions, by depreciation, by alterations in interest rates, but which must be taken as con-

stant for our purpose. This cost element, therefore, depends on the quantity of units produced, and therefore on the « utilisation » of the available plant.

Utilisation.

The idea of « utilisation » can be defined by comparing what *has been* done or made with what *could have been* carried out or produced, in the time available with the materials and labour to hand. It can be expressed by the equation :

$$\frac{\textit{Actual}\ \text{quantity}}{\textit{Possible}\ \text{quantity}} = \frac{\textit{Actual}\ \text{work}}{\textit{Possible}\ \text{work}}\ \text{in unit time} \times \frac{\textit{Actual}\ \text{service life}}{\textit{Possible}\ \text{service life}}$$

This equation can be written :

Utilisation = Intensity factor $\times$ Time factor [1].

In the above we are to understand by

Actual quantity and *Possible* quantity: the number of units produced in the period considered, or of those which could have been produced therein, had complete use been made of the plant available and the possible working period.

and in the same way by :

Actual work and *Possible* work: the actual production or the maximum production possible for the available equipment in unit time.

Actual working period and *Possible* working period: the actual working period or the longest possible working period.

The element « capital charges » in the equation giving the unit cost can therefore be written :

$$\frac{\text{Capital charges}}{\textit{Possible}\ \text{quantity}} \times \frac{1}{\text{Intensity factor } i} \times \frac{1}{\text{Time factor } z}$$

i.e. equal to the best obtainable value divided by $i \times z$. These two values indicate the material and temporal utilisation and, as we have explained, directly affect the part of the capital charges chargeable to the unit of industrial production or work carried out.

To make it easier to understand these ideas, let us quote some *examples taken from railway operation :*

Example of the utilisation of a line :

$$\frac{\text{Capital charges } k \text{ per km. operated}}{\text{Train-km. per km. operated}} = \frac{k}{\textit{Possible}\ \text{train-km. per annum per km. operated} \times i \times z}$$

wherein :

$$\text{the intensity factor } i = \frac{\textit{Actual}\ \text{train-km. per day and per km. operated}}{\textit{Possible}\ \text{train-km. per day and per km. operated}}$$

$$\text{and the time factor } z = \frac{\textit{Actual}\ \text{train-hours}}{\textit{Possible}\ \text{hours per annum.}}$$

(1) Ideas and notations taken from K. Rummel's excellent book « *Grundlagen der Selbstkostenrechnung* » (Principles of the calculation of cost prices), Stahleisen, 1934 edition.

Example of the commercial utilisation of the locomotives:

$$\frac{\text{Capital charges } k \text{ of the locomotive stock}}{\textit{Actual} \text{ number of engine-km. run annually}} = \frac{k}{\textit{Possible} \text{ locomotive-km. per annum} \times i \times z}$$

wherein :

$$i = \frac{\textit{Actual} \text{ locom.-km. per day per locom.}}{\textit{Possible} \text{ locom.-km. per day per locom.}} \times \frac{\text{Number of locom. used}}{\text{Number of locom. in working order}}$$

$$z = \frac{\textit{Actual} \text{ locomotive-days per locomotive and per year}}{\text{Calendar days}}$$

The structure of these notions shows that :

1. It is essential to calculate the « *possible* output » and the « *possible* time » if the degree of utilisation is to be ascertained. Two methods can be followed :

a) The maximum theoretical utilisation of an undertaking or its components is ascertained by applying the peak results obtained from a set of equipment (for example the density of traffic on a section of line or the mileage of a locomotive) in the usual unit of time (day, hours, etc.) to the other equipments of like nature and over the whole year. The « *possible* values » thus obtained would have to be calculated for each year, as the peak results used vary according to the technical methods and organisation, as well as the financial position. This method involves a differentiation, i.e. the equipments, which by their nature should be considered in connection with the peak results considered, must be grouped together. As regards organisation, traffic, operating, and technical services, the groups can be further subdivided as desired.

b) Without going into details, the maximum values observed during a number of years for the whole undertaking, or its component parts, or its classes of traffic, for example during a period of peak activity, are ascertained, and the utilisation is calculated therefrom as a basis of comparison with the results of other years. This comparison with years of great prosperity is also commonly used on other occasions to show changes in the economic position.

Method (*a*) gives for each year possible values and degrees of utilisation revealed by the year's results on an analysis of the structure of the undertaking, whereas method (*b*) shows the changes which took place in the course of the years considered. The practical examples given below are based on method (*b*).

2. The utilisation can vary with the different conditions, as is shown by resolving it into its intensity and time factors.

It increases and decreases directly *as* the intensity and period of service, i.e. with the numerators of i and z. The cause may be a change in the economic position (increased or reduced consumption) or a decrease in the traffic due to competition from other methods of transport).

But the utilisation varies inversely, i.e. it rises or drops with the fall or rise of the possible work or of the possible duration of service, in other terms with the denominators of i and z. If by improved technical methods or better organisation the possible production is increased, then this must be justified by a corresponding increase in the quantities produced as otherwise the utilisation becomes poorer. So as to reduce the proportion of capital charges in the cost price, or to prevent them from becoming excessive through the costs of technical improvements, out of date equipments must be completely eliminated and their capital value cleared from the capital account of the undertaking. Equipment of this kind taken out of service can be re-

tained in reserve to meet unexpected demands but only to the extent that little cost is involved in doing this and in putting it into good order.

As regards the variation in utilisation it should be remembered in each case that, unlike a manufacturing company's output, the product of a railway, namely transport, cannot be stocked, or in other words, the production must correspond at all times to the consumption as compensation cannot be obtained by putting into stock. In many cases, however, the consumption can be controlled in a compensatory way by reorganisation measures or by rates adjustments and the utilisation improved thereby.

The relation between the utilisation of the equipment and the economic employment of the capital which we have just touched upon, is most important in connection with the division of traffic as between rail, road, and air, and the intensification of railway working which results therefrom.

3. The intensity and time factors, even in fields not directly related to the capital charges, provide valuable information for making comparisons as the following examples, taken from the organisation of the staff, show.

The utilisation of the workmen paid by the hour can be expressed by the equation :

$$a = \frac{\text{Workmen's hours}}{\text{Number of men} \times \times \text{ number of hours par annum}}$$

in which :

Workmen's hours means the total hours worked or paid for in accordance with the agreements in force;

Hours per annum means the hours in a year, or rather this number after deducting the hours on Sundays and holidays.

We can make :

$$a = \frac{\left(\frac{\text{Workmen's hours}}{s \times \text{Working days}}\right)}{\text{Number of workmen}} \times \frac{s \times \text{Working days}}{\text{Hours per annum}}$$

wherein

s = the hours in a turn of duty.

Working days = the number of days the men could work, i. e. in which the works or yard was open ;

$s \times$ working days = the working hours.

Referred to one month, the relation

$$\frac{\text{Workmen's hours}}{\text{Working hours}} \text{ or } \frac{\text{nombre total de jours de travail}}{\text{jours ouvrables}}$$

is described as homme-mois (men-days) (the French expressions are those used in the annual report of the Belgian State Railways.)

The intensity factor $i = \frac{\text{men-days}}{\text{number of men}}$ represents the intensity of occupation of the men employed,

the time factor $z = \frac{\text{hours of work}}{\text{hours per annum}}$ shows the time basis on which this occupation takes place and especially the length of the turn of duty.

Changes in the length of the turn of duty are not reflected in the intensity factor i. If, for example, this period be shortened from 9 to 8 hours and if the number of men employed increases as 8 to 9, i retains the same value. The utilisation of the men's capacity is only discernable when adding the time factor, in which the period of the turn of duty is a function of the calendar time.

Similar remarks apply to men whose *possible* time of occupation is not fixed or limited by the hours or days of work

at the place of work, but by legal or administrative regulations about hours of duty, such is the case, for example, of the locomotive running and operating staffs. We then have

$$a = \frac{\textit{Actual}\text{ working hours}}{\text{Number of men} \times \text{hours per annum}} \text{ or } \frac{\left(\dfrac{\textit{Actual}\text{ working hours}}{\textit{Possible}\text{ working hours}}\right) \times \dfrac{\textit{Possible}\text{ working hours}}{\text{Hours per annum}}}{\text{Number of men}},$$

an expression in which the first term represents the intensity factor, and the second the time factor, and in which by *possible* working hours is to be understood the period of work allowed by the regulations.

The ratio of the *actual* to the *possible* working hours shows how far the regulations on hours of work are observed or ignored.

II. — Application to statistics.

With few exceptions, the time factor is more or less disregarded in railway statistics. We will quickly examine below the information to be found in the official statistics published by the different Railway Companies.

1. Utilisation of available labour.

The number of officials or staff is generally shown in units and that of the workmen by men-days (or men-months). Like the first indication, the second gives a scale for calculations in money, so long as the « workmen's-hours » (see above sub. I, 3) are considered as hours actually paid for, because a man-day then becomes the basis of the cost of a workman fully occupied and paid during one month. The number of men at work is rarely given, but is no doubt constantly controlled, seeing that it is the determining factor in certain expenditure which does not depend on the work done (administration, social work, technical services, etc.).

The only full information we have been able to find was in the *Statistics of Railways in the United States* of America. A distinction is made between men paid on a *daily basis* and on an *hourly basis,* with subdivision by classes of occupation, such as in administrative duties, maintenance work, traffic or traction departments, etc., with particulars of the average number of staff employed, regular hours, overtime, etc., and the sums paid. The utilisation of the working capacity of the staff occupied in the different branches of the service can be calculated from these figures. For comparisons (abandoning the relation to the hours of work as possible value) the number of hours or days worked by an employee given in the returns can already be used.

If the usual hours of duty — not shown, it is true — are added, the intensity factor and time factor can be calculated separately.

In these statistics the side issue of men-days has been ignored. The average number of hours paid or the average amount of wages paid per man provide directly the monetary scale for the budget and budget control, as well as, in general, for calculations of a financial nature, the usual working period of the centre, the rates of pay and salaries in force being taken into account.

Other information is also given on the period of occupation, but only to compare it with the work *actually* done.

The hours of the men in the sheds, en-

gaged on repairs, is often given as in the Italian and Belgian annual reports, with the corresponding time the vehicles are out of service. The Belgian Railways also give the man-hours spent in permanent way repairs with particulars showing the extent of the work and the materials used, such as renewing rails and sleepers, or rails only.

Such information is of doubtful value as regards working costs. The varying importance of the work done, which depends on the actual conditions (such as type of stock, class of work required from it, etc.), is not known, nor the different ways the work is organised (preparatory work, mechanisation, etc.). Consequently the data on the men-hours required can only be used as the basis on which to estimate the *average* cost of the projected work, as regards labour required and salaries, and the part such wages play in the total cost of the work.

2. Utilisation of available installations and equipment.

As in the case of labour, the output depends on the organisation and technical conditions. The notion of « *possible* work » *in a period* is based on the working capacity, i.e. on the maximum possible production in unit time.

This conception at once demands an answer to the question of the time spent on the *actual* work. Because of this connexity, information on any kind of annual production, without indication of the time, is not sufficient for the utilisation of the installation to be appreciated, even when divided — as usual — according to certain traffic and operation constants (namely by districts and classes of train). Now this division is, in fact, due to the need of taking — at least approximately — local circumstances and traffic and operating conditions into account, in other words, the particular character of the work in question, i.e. of the need for introducing the notion of the capacity of production or of « *possible* work ». The traffic density, for example, will be considered differently in an industrial area and a mountain district with a scattered population. The same applies in the case of the number of axles on a passenger train and that on a goods train. The tractive effort the locomotive can develop as well as its utilisation, the varying speeds and the particular nature of the line will have to be considered as well.

In this connection, the presumption is that the Railways currently compare, for their own purposes, the capacity (the *possible* work) with the actual production (*actual* work done) as this is the only means they have of making sure that the arrangements they have made (in the last two examples : proper distribution of trains over the different lines, dimensions and scientific use of locomotives, etc.) were adequate.

These reflections apply generally to all branches of the railway service, whether goods or passenger traffic, shunting yards, rolling stock, workshops, etc.

The railways seldom give information on their possible capacity. As an example, the Belgian National Railways give the programme (or *possible*) mileages as well as the *actual* mileages between repairs, separately for passenger, goods, and shunting locomotives.

The information generally fails to give the time required for the different kinds of work. Obviously, no theoretical argument is required to show the capital importance of knowing if a work has been done in a certain time with the equipment only half used, or in half the time with the equipment fully employed.

The rational organisation referred to above will sooner or later be reflected in the financial position, i.e. in the oper-

ating expenditure and in the cost prices, as well as in the capital accounts and balance sheet.

The *sole* exception we have come across is the

Returns of the Railway Companies of Great Britain!

These Returns give the hours of service by class of service (steam traction, electric traction, and rail motor cars) and by class of work (passenger trains, goods trains, shunting, and other ancilliary locomotive services). Then too the train-miles, which is the production of the operating department, grouped by class of service and kind or work, are given in terms of engine-hours and train-hours. From this information and other statistical data, the constants for certain fields can be calculated.

The only examples we will deal with here are :

1. Utilisation of steam locomotives:

$$\text{Intensity factor } i = \frac{\text{Miles run by the locom. daily}}{\textit{Possible} \text{ daily mileage}} \times \frac{\text{Number of locom. in service}}{\text{Locom. in working order}}$$

$$\text{Time factor } z = \frac{\text{Daily locomotive-hours (for example on a working day).}}{\textit{Possible} \text{ hours}}$$

2. The utilisation of the goods wagons:

$$\text{Intensity factor } i = \frac{\textit{Actual} \text{ load per axle of the loaded wagons}}{\textit{Possible} \text{ axle-load}} \times \frac{\text{Mileage run by the loaded wagons}}{\text{Mileage run by all wagons}}$$

(As the intensity factor should not be a function of the number of loaded wagons, the weight per axle of which is known, but of all the wagons in actual use, it must be multiplied by the ratio of loaded-wagon-miles to the total wagon-miles.)

$$\text{Time factor } z = \frac{\text{Train-hours} \times \text{Number of wagons per train}}{\textit{Possible} \text{ hours} \times \text{Number of wagons in service}}$$

The evaluation of the *possible* hours and of the *possible* work is impossible for anyone outside the undertaking. They may be fixed for domestic purposes, for example as limiting values in determining the ideal budget. Even without knowing them, the variation in time of the utilisation values can, however, be shown if the possible values for a Company over a series of years are supposed to be constant over the period.

If the equations given above for i and z be multiplied on both sides by the unknown, but invariable, possible values C_i and C_z we get the values ($i \times C_i$) and ($z \times C_z$) by means of which the times for any particular Company can be compared.

As an exact idea is only possible by making a series of comparisons, the calculations for the above two examples over the years 1928 to 1933 are given below.

In the case of the four British Main Line Companies, the values ($i \times C_i$) and ($z \times C_z$) and their product ($C \times i \times z$) = ($a \times C_a$) are given in Tables I and II. Owing to the differences in the *possible* values C as already pointed out, the absolute results cannot be used to make comparisons *between* the Companies (or only by taking into account the particular characteristics of the undertakings based on exact knowledge of their organisation). It is possible, however,

to compare the relative changes shown in the last part of the tables, relatively to 1928, the results of which are taken as 100 %. If the changes are to be properly understood, it is necessary to refer back to the original figures, which have not been reproduced here through lack of space.

TABLE I.

Utilisation of steam locomotives.

—	—	Southern Ry. (1)	Great Western Ry. (2)	London-Midland & Scottish Ry. (3)	London & North Eastern Ry. (4)
$(i \times C_i) = \frac{\text{Engines in use (all services)}}{\text{Engines available for use}} \times$ Engine-miles per day per engine in use (weekdays).	1928	110.5	98.4	85.5	87.9
	1929	109.5	100.0	85.9	88.7
	1930	108.0	98.4	84.5	91.0
	1931	107.4	96.5	88.5	88.7
	1932	106.5	96.0	92.1	86.4
	1933	112.0	100.0	97.5	88.8
$(z \times C_z) =$ Engine-hours « in traffic » per engine in use per day (weekdays).	1928	12.04	12.73	11.15	12.28
	1929	11 94	12.88	11.37	12.67
	1930	11.92	12.54	11.15	12.28
	1931	11.96	12.31	11.47	12.01
	1932	11.86	12.07	11 54	11.63
	1933	12.19	12.38	11.99	11.92
$(i \times C_i) \times (z \times C_z) = (a \times C_a)$ absolute value	1928	1 330	1 251	952	1 076
	1929	1 310	1 288	976	1 120
	1930	1 290	1 232	945	1 115
	1931	1 285	1 189	1 001	1 065
	1932	1 262	1 156	1 062	1 005
	1933	1 360	1 238	1 170	1 055
" " relative value 1928 = 100 %	1928	100	100	100	100
	1929	98.5	102.6	102.5	104
	1930	97	98.5	99	103.5
	1931	96.5	95	105	99
	1932	95	92.4	111.5	93.5
	1933	102	98.8	123	98.4

Remarks on Table I.

Utilisation of steam locomotives.

The utilisation has only improved continuously (except for an interruption in 1930) on railway No. 3, unlike on all the railways considered.

The various figures show that on railway No. 3 alone the ratio of the locomotives in use to those in working order, the miles per

day and the hours per day have increased, whilst on railways Nos. 1, 2 and 4, although the miles per day have increased on railway No. 1 and remained the same on railway No. 4 the other values have fallen.

A sudden improvement on all the railways and in all the values is recorded from 1932 to 1933. The explanation why the changes have taken place in a different way on railway No. 1 than on the other railways is to be found in the remarks on the goods wagons.

TABLE II.

Utilisation of goods wagons.

—	—	Southern Ry. (1)	Great Western Ry. (2)	London-Midland & Scottish Ry. (3)	London & North Eastern Ry. (4)
$(i \times C_i) = \dfrac{\text{Average wagon loads (all freight per loaded wagon)}}{\text{Capacity of traffic-carrying vehicles (total average per wagon)}} \times \dfrac{\text{Freight wagon-miles loaded}}{\text{Miles, total}}$	1928	0.32	0.349	0.346	0.324
	1929	0.323	0.363	0.343	0.326
	1930	0.326	0.355	0.337	0.318
	1931	0.322	0.344	0.324	0.310
	1932	0.315	0.340	0.320	0.304
	1933	0.306	0.342	0.313	0.300
$(z \times C_z) = \dfrac{\text{Train-hours (freight), total} \times \text{Wagons per train, total}}{\text{Wagons in stock}}$	1928	672	1 140	795	710
	1929	740	1 238	839	786
	1930	711	1 135	779	725
	1931	695	1 025	726	656
	1932	655	936	655	580
	1933	665	975	690	621
$(i \times C_i) \times (z \times C_z) = (a \times C_a)$ absolute value	1928	215	390	275	250
	1929	239	450	287	256
	1930	232	404	262	230
	1931	224	352	235	204
	1932	206	318	210	176
	1933	201	334	216	186
" " relative value 1928 = 100 %	1928	100	100	100	100
	1929	111	115.5	104.4	102.5
	1930	108	103	95.2	92
	1931	104	90.5	85.5	81.5
	1932	96	81.5	76.5	70.5
	1933	93.6	85.6	78.6	74.5

Remarks on Table II.

Utilisation of goods wagons.

From the statistical point of view, i.e. by means of the basic figures, the differences in the utilisation of the wagons can be explained as follows:

From 1929, the year of maximum values, to 1932, the ratio of the useful load to the loading capacity fell 6 to 7 % on railways

Nos. 2, 3 and 4, and rose slightly on railway No. 1. On the other hand, the mileage of loaded wagons to that of all wagons remained more or less constant. The number of wagons per train fell only very slightly (the greatest drop being 5.3 % on railway No. 2). The train-hours have increased by 22 % on railway No. 2, by 25 % on railway No. 3, by 27 % on railway No. 4, and only 7 % on railway No. 1. They exerted a decisive influence on the set-back of the time factor (in the denominator of which the « stock » has only decreased slightly), and thereby the whole of the utilisation.

The *organic cause* why railway No. 1, as regards goods wagons, shows quite different results from the others is due to the structure of the undertaking and the nature of the bulk of the goods carried.

TABLE III.

Variations in goods traffic.

—	—	(1)	(2)	(3)	(4)
Wagon-miles, total . . .	1928 Mill.	221.493	846 953	2 008.878	1 632.431
	1928 = %	100	100	100	100
	1929	104	105	103	106.5
	1930	102	101.2	98.8	102
	1931	101.5	94	93.5	94.6
	1932	97.5	87.5	87.6	86.2
	1933	97.4	88.8	87.5	88.5

If the total wagons-miles run are expressed relatively to those of 1928 taken as 100, table III shows that railway No. 1 is much less affected by trade fluctuations than the others. Railway No. 1 also had a 104 % peak in 1929, but was exceeded by railways Nos. 2 and 3, and fell much more slowly than the others until 1933.

TABLE IV.

Variations in goods traffic in full wagon loads.

—	—	(1)	(2)	(3)	(4)
Total net Ton-miles worked. (Minerals and merchandise Cl. 1-6 and Coal, coke, patent fuel.)	1928 Mill.	467.7	2 277.1	4 940.7	4 188.8
	1928 = %	100	100	100	100
	1929	110.2	109.2	105	112
	1930	109.5	101	99	105.5
	1931	110.4	89 5	91.8	96
	1932	106	84.0	84.6	86.2
	1933	105	85.4	83.1	87.8

These variations are explained in table IV, in which the variation in goods particularly sensitive to trade fluctuations (classes 1 to 6 minerals and

goods, and solid fuel) are given relatively to 1928 taken as 100 (in total net ton-miles worked and not in wagon-miles). Such traffic in full wagon loads declined much more on railways Nos. 2, 3 and 4 than on No. 1, and this unfavourably affects the utilisation of the wagons. Then too, the fact that on railway No. 1 the ton-miles were proportionately less than on the others (64 to 68 % against 68 to 72 % in the years considered) is not enough to neutralise this effect.

TABLE V.

Utilisation of the electric motor vehicles on the Southern Railway.

ELECTRIC MOTOR VEHICLES.	1928	1929	1930	1931	1932	1933
(1) Miles per day per vehicle in use (weekdays)	213.94	229 05	243.23	247.55	243.96	238.1
(2) Daily average number on weekdays « in use » : « available for use »	0.936	0.944	0.950	0.966	0.960	0.986
(3) Hours « in traffic » per day per vehicle in use (weekdays).	10.84	11.51	12.15	12.44	12.44	11.94
(4) $(i \times C_i) = (1) \times (2)$. . .	200	216	231	249	234	237
$(a \times C_a) = (3) \times (4)$. . .	2 168	2 490	2 810	3 100	2 920	2 830
1928 = 100 %	100	115	129.5	143	134.5	130.5

Remarks on Table V.

Variations in connection with the Southern Railway Company's electric rolling stock.

The Southern Railway traffic differs from that of the three other Companies: 75 % of the operating receipts are from passenger and parcels traffic (on the others the figures are 42.8, 41.8, and 36.8 %), and 45.3 % of the passenger train-miles and 40.4 % of the total traffic-miles is worked by electric motor vehicles, which therefore play a specially important part. The variations are given in Table V on the same lines as in the case of steam locomotives.

The basic figures quoted here make it possible to recognise at once the influences by their effect on the final result, the utilisation factor and its variations.

It will be sufficient for our purpose to point out that the daily mileage of a rail motor car, and the time it is in service per day have fallen off in the last two years, whereas the proportion of rail motor cars used during the week to the number of such vehicles in working order has increased.

Conclusion.

These theoretical considerations and practical examples show the importance to be given to the notion of « *Utilisation* » and consequently to the « *Intensity factor* » and the « *Time factor* ».

As a rule the latter is not given sufficient attention in statistics. These constants supply essential data when dealing with the statistical and financial aspects, and enable the operating results to be studied effectively.

With the mechanisation of the work in connection with accounts and statistics (Hollerith and Powers perforated-card systems) now so much used, the time factor can be ascertained quite easily, as is frequently done in the case of wages.

[625.61]

Narrow-gauge main-line railways (*)

by P. KANDAOUROFF, Engineer.

I. — General considerations.

Narrow-gauge railways, in Europe and North America, are nearly always thought of as local railways or secondary railways. Generally speaking, this point of view is justified in these countries as the only railways of less than the standard 4′ 8 1/2″ gauge are local or secondary lines. When the traffic on such lines increases to any appreciable extent, they are converted to the standard gauge (1).

Then too, the opinion that larger gauges than the standard 4′ 8 1/2″ are the only ones able to handle large volumes of traffic and high-speed traffic and that the capacity of a railway depends upon the gauge of the track is very widely held.

If, however, the railways of other countries are studied, we see that narrow-gauge lines can also be *main lines* of high efficiency, providing frequent and fast train services.

At the present time there are many countries with considerable mileages of railways of less than 4′ 8 1/2″ gauge. These railway systems are, it is true, less important than the European and American systems (2). They are nonetheless very extensive and serve territories the area of which bears comparison with that of the whole of Europe. Table 1 shows the distribution of the largest metre (3′ 3 3/8″) and Cape (3′ 6″) gauges, the latter so called because first used in Cape Colony. Practically speaking these two gauges are the same (3).

In addition to these lines, of a definitely main-line character, there are others outside Europe which, although they can be considered more or less as

(*) For convenience and brevity, the term « main lines » is used to designate what in German is called « Hauptbahnen » or principal railways, in opposition to « Nebenbahnen » or secondary railways, coming under easier regulations as regards construction of the track, signalling, etc. More or less the same distinction is made in France between « chemins de fer d'intérêt général » and « chemins de fer d'intérêt local » *(Translator's note)*.

(1) Although the 4′ 8 1/2″ gauge is considered as the standard, in this article the predominant gauge of a country is considered as its standard gauge. The most notable exception is Russia and certain neighbouring countries where there are over 52 000 miles of 5-foot gauge railways.

The difference of only 3 1/2 inches between the standard and the Russian gauge is so little that the wheel sets of the stock can be changed so as to avoid transhipment of heavy loads.

(2) The largest railway systems of the World which can be operated with a common stock of vehicles are the following :

North American (United States, Canada, Mexico) .	342 000 miles.
Western Europe (excluding Spain and Portugal) . . .	134 000 miles.
Russian-gauge lines (U.S.S.R., Finland, new neighbouring States, and Eastern Chinese)	52 000 miles.

(3) The economic importance of narrow-gauge railways has been expounded by Professor Blum in his article « Trassierungs-Grundsätze fur Eisenbahnen ausserhalb der hoch-industrialisierten Gebiete » (Principles of the location of railways lying outside highly industrialised regions). *Verkehrstechnische Woche*, 1933, pp. 537 et seq.

main lines, are of comparatively short length.

Table I shows that some of these railway systems, such as those of Japan, and Java, are quite as dense as the Polish and Rumanian systems. Some others, such as those of Australia and New Zealand, are very extensive relatively to the population.

There are also in Europe two narrow-

TABLE 1.

The most important narrow-gauge railway systems in the World.

Name of country and description of railway system.	Gauge.	Total length of railways, miles.	Total area of country in thousands of sq. miles.	Population, in thousands of inhabitants.	Length of lines per 100 square miles.	Length of lines per 10000 inhabitants.	Population per sq. mile.
Union of South Africa and neighbouring countries (4)	3′ 6″	17 940	2 720	21 819	6.60	8.14	8.03
Sudan	Do.	1 990	1 010	7 006	0.19	2.81	6.7
Nigeria	Do.	1 597	336	18 766	0.48	0.85	57.0
Japan	Do.	12 822	147	64 825	8.71	1.99	439 3
Formosa	Do.	890	14	3 995	6.41	2.24	287.0
Java	Do.	3 410	51	34 984	6.70	0.93	389.0
Philippine Isles.	Do.	726	114	12 400	0.63	0 58	108.8
Australia :							
Queensland	Do.	6 537	671	912	0 98	65 21	1.37
West Australia	Do.	4 182	976	400	0.43	104.51	0.41
South Australia	Do.	1 883	380	578	0.50	32.60	1.53
Tasmania	Do.	778	26	210	2.74	34.09	8.0
New Zealand	Do.	3 314	102	1 525	3.24	21.74	15.0
Newfoundland	Do.	953	163	267	0.64	35 65	1.6
Brazil	3′ 3⅜″	12 200(*)	582	19 388	2.09	6.27	33.2
Argentina	Do.	7 300	375	2 249	1.96	32.60	6.0
British India							
Northern System	Do.	9 800(5)	...	...	...	...	...
Southern System	Do.	4 200	...	...	..	...	...
Burma	Do.	1 973	234	13 212	0.84	1.49	54.7
Siam and Malay States.	Do.	2 950	295	15 706	1.00	1.86	53 6
Indo-China and Yunnan.	Do.	1 480	1 271	20 000	0.43	0.56	73.8
Tanganyika	Do.	1 280	363	4 323	0.35	3.35	11.9
Kenya and Uganda	Do.	1 560	291	5 874	0.53	2.65	20.2

(4) Rhodesia, the former German South West Africa, the Portuguese South African Colonies on both coasts, and part of the Belgian Congo, which are served by railways of the Cape gauge.

(*) Separate system with through traffic.

(5) The metre-gauge lines in British India are so interlaced with the broad gauge system that no indication as to area and population served by them can be given.

gauge systems which must be included amongst the main lines; these are the metre-gauge lines in south-eastern Switzerland, the Rhætian Railway with the small lines directly connected with it, the total length being some 286 miles, and the 2′ 6″ gauge lines of Bosnia-Herzegovinia of a total length of about 1 400 miles.

II. — Rolling stock.

Had we possessed our present technical knowledge when railways were introduced, the vehicles would have been much better designed as regards cross section. The railway is over 100 years old and represents a progressive growth, the present state of technical knowledge being the result of observation and investigation in this special field.

Logically the width and height of the vehicles, the principal factors of the constructional gauge, should be directly proportional to the gauge of the track. In actual practice this is quite otherwise. Both the contour of the constructional gauge and the gauge of the track were selected quite fortuitously, especially as regards the standard gauge which being fixed at 4′ 8 1/2″ is not even a round number in English measures, and still less so in the metric system. Round numbers (6) were only adopted at a later date when introducing other gauges.

The rolling stock gauge too was usually determined haphazardly so that the chief dimensions, the maximum width and height, bear no direct relation to the gauge of the track, as table 2 shows.

The width of the body is particularly important as regards the passengers' comfort. Table 2 and figure 1 show that

TABLE 2.

Gauge.	RAILWAYS.	Loading gauge.		Ratio.		Maximum width of passenger vehicle bodies.
		Maximum height.	Maximum width.	Height / gauge.	Width / gauge.	
5′ 3″	Ireland	14′	10′ 8″	2.67	2.03	9′
5′	U. S. S. R.	17′ 2 11/16″	11′ 2 1/4″	3.44	2.25	10′ 2 5/16″
4′ 8 1/2″	England	13′	9′	2.78	1.91	9′
»	Berne Convention.	14′ 1/2″	10′ 2″	2.98	2.16	10′ 1 10/16″ (7)
3′ 6″	Java	12′ 3 10/16″	10′ 1 1/4″	3.52	2.89	8′ 8 3/4″
»	Japan	13′ 3″	9′ 10″	3.75	2 81	9′ 2 1/4″
»	South Africa	13′	10′	3.72	2.86	9′ 3″
3′ 3 3/8″	Rhætian Railway	12′ 1 10/16″	8′ 10 1/2″	3.70	2.70	8′ 6 6/16″
»	Siam	12′ 5 10/16″	9′ 2 1/4″	3.80	2.80	8′ 6 6/16″
2′ 6″	Jugoslavia	11′ 11 11/16″	8′ 2 1/16″	5.14	3.29	7′ 10″

(6) 5′ 6″ for Spain, Portugal, and British India. 5′ 3″ for Ireland, parts of Brazil and Australia, Russia, and Finland, 3′ 6″ (the Cape gauge), 1 metre (3′ 3 3/8″) for many colonial and secondary lines, 3′, 2′ 6″, etc. Gauges exceeding 5′ 6″, the most important of which was the English Great Western, had disappeared completely before the beginning of the century.

(7) For the German State Railways.

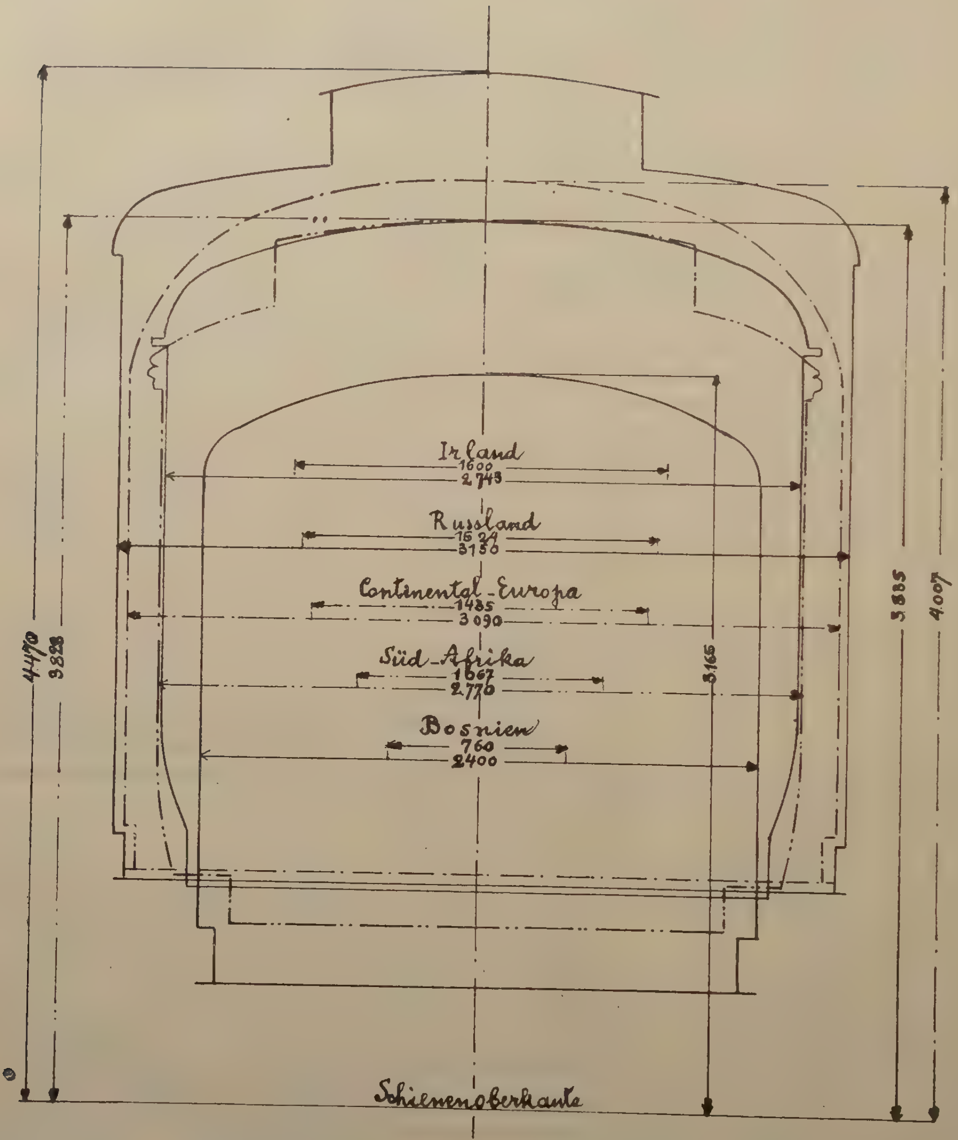


Fig. 1.

Note. — Schienenoberkante = Top of rail.

(Table 2 shows the equivalent dimensions, in feet and inches, of the track gauges and loading gauges).

the width of the body of passenger vehicles does not differ very much on the various railways and that, from this standpoint, the gauge is far from having the great importance one might be tempted to give it. Vehicles on many 3′ 6″ and metre-gauge lines are wider than those used in England. The bodies of passenger vehicles on the Bosnia-Herzegovinia railways, the gauge of which is about half the standard, are only about 13 inches narrower than in England.

If in the United States of America and on the European Continent, the vehicles are somewhat wider than those running on the 3′ 6″ and metre gauges, the difference is slight, so that we can say that generally speaking the latter vehicles can be made perfectly comfortable, in fact can be luxurious.

A journey in Japan, Java, and South Africa is quite as comfortable as on the best European or American railways.

In the same way the tare and loading capacity of goods vehicles per foot of gauge, and the ratio of these weights, are almost independent of the gauge of the track, as shown by table 3.

As regards narrow-gauge locomotives, the narrow-gauge main lines have nearly as powerful and heavy locomotives as the standard-gauge lines, as is shown in table 4, and they are able to attain very high speeds.

TABLE 3.

NAME OF RAILWAYS AND DESCRIPTION OF WAGONS.	Number of wheels.	Gauge.	Length over buffers.	Tare. lb.	Loading capacity. lb.	Total weight. lb.	Tare per foot of overall length. lb.	Total weight per foot of overall length. lb.	Tare / load. %	Maximum axle load. lb.
German State :										
Covered wagons . . .	4	4′ 8 1/2″	30′ 6″	23 150	33 070	56 220	1 083	1 842	70.0	28 110
Open wagons	4	»	37′ 9″	20 950	33 070	54 020	875	1 430	63.3	27 000
Coke wagons	8	»	39′ 4 1/2″	49 600	126 760	176 360	3 210	4 470	39.1	44 100
Japanese Government (8) :										
Covered wagons . . .	4	3′ 6″	25′ 8 1/4″	20 500	33 070	53 570	1 283	2 042	62.0	26 790
Open wagons	4	»	29′ 9″	20 280	37 480	57 760	1 330	1 880	54 2	26 100
Self-discharging wagons	8	»	28′ 7″	33 730	66 140	99 870	2 310	3 485	51.0	26 070
Union of South Africa :										
Open wagons	12	»	45′ 9 1/4″	69 000	152 000	221 000	3 360	4 860	44.8	37 200
Open wagons	8	»	42′ 10″	47 700	100 000	147 700	2 330	3 440	47.7	36 930
Cattle wagons . . .	8	»	40′	42 750	60 000	102 750	1 500	2 560	71.4	25 240
Covered wagons . . .	4	»	25′	21 640	40 000	61 640	1 600	2 460	53.3	30 800
Siamese State :										
Covered wagons . .	4	3′ 3 3/8″	24 1″	17 200	27 560	44 760	1 140	1 850	62.4	22 380
Open wagons	8	»	32′ 9 11/16″	17 730	44 090	61 820	1 344	1 610	40.2	15 450
Self discharging wagons	8	»	31′ 9 7/16″	36 160	60 630	96 790	1 910	3 040	59.7	24 200

(8) The data on the Japanese Government Railways has been taken from the article by PUTZE in the *Organ für die Fortschritte des Eisenbahnwesens*, 1931, pp. 247 and 265.

TABLE 4.

Description of locomotives.	Maker.	Gauge.	Wheel arrangement.	Weight in working order, with tender. lb.	Adhesive weight. lb.	Tractive effort with 75 °/o cut-off. lb.	Weight in working order, per foot of length. lb.
German State.							
1. Class 02	Various German Locom. Works.	4′8 1/2″	4—6—2	400 360	132 500	45 240	5 130
2. Class 44		»	2—10—0	404 770	211 640	58 900	5 450
Japanese Govt.							
3. Class C 53 . . .	Japanese Locom. Works.	3′ 6″	4—6—2	286 550	102 000	26 520	4 220
Union of South Africa.							
4. Garratt locom. . .	Maffei.	»	4—6—2+ 2—6—4	413 360	246 920	44 250	4 850
5. Express locom. . .	Baldwin.	»	4—6—2	334 000	116 840	30 600	4 700
6. » » . .	North British Locomotive Co.	»	4—8—2	385 580	157 230	38 980	5 220
Javanese State.							
7. Javanic	Hanomag.	»	2—12—2	165 345	125 660	26 785	3 580
8. Mallet	»	»	2—8+8	307 100	194 000	62 830	4 420
9. Express locom. . .	Dutch Locom. Works.	»	4—6—2	240 530	80 910	22 700	3 530
Siamese State.	Hanomag.	3′3 3/8″	4—6—2	197 530	69 445	19 310	3 300
North Eastern of Brazil.	Borsig.	»	4—8—2	233 000	116 840	27 950	3 600
Jugoslav State	»	2′ 6″	2—6+6	112 215	99 430	31 970	3 400

Table 4 also shows that there are narrow-gauge locomotives differing very slightly from the most modern German locomotives as regards tractive effort and adhesive weight.

The narrow-gauge locomotives have much increased in size especially since the War, and the development of such locomotives, notably in South Africa, has been greater than on the standard-gauge lines. For example the « Javanic » 2-12-2 locomotive built by the Hanomag Works in 1912 for the Javanese State Railways, which at that time was one of the most powerful 3′ 6″ gauge locomotives, was followed 12 years later by an even more powerful one, as shown hereafter :

—	Javanic 1912.	Mallet 1924.	Increase. °/o
Total weight . . lb.	165 345	307 100	85.7
Adhesive weight . lb.	125 660	194 000	60.0
Maxim. axle load . lb.	20 040	24 250	15.8
Tractive effort . . lb.	26 725	62 830	134.5
Horse power . . .	1 230	2 260	83.7

The most powerful 3′ 6″ gauge locomotives are those of the South African Railways. The Japanese Government locomotives are smaller although this railway system has a most dense traffic, in fact almost the densest in the world. The train weights in Japan are, however, relatively low.

As regards electric traction, very powerful locomotives are in use on both the Cape and metre gauges, and there is no reason why their future development should not be as great as on standard and broad-gauge lines. For example, the South African Railways have 1 200-H.P. eight-wheeled locomotives weighing 66 tons, which are are so designed that triple heading can be resorted to, when they can haul a train of 1 600 tons up 1 in 100 at a speed of 21.7 miles an hour which is reached in 3 minutes after starting on this gradient (9).

The standard 4-6 + 6-4 Japanese locomotives develop 1 830 H.P. and weigh 106 tons with an adhesive weight of 79.1 tons (10).

III. — Stability of the vehicles.

The stability of narrow-gauge vehicles, especially that of the modern locomotives with their high centre of gravity, might be thought to be below that of standard or broad-gauge vehicles, so that the speed should be lower on the Cape or metre-gauge lines. This remark applies especially to curves, as on the straight the speed is practically unlimited so far as the stability of the vehicles is concerned.

As basis of comparison, we will take the class 01 and 03 standard locomotives of the German State Railways.

(9) *Schweizerische Bauzeitung*, Vol. 83 (1924), p. 115.

(10) *Organ für die Fortschritte des Eisenbahnwesens*, 1931, p. 251.

The superelevation of the track will be given by the theoretical formula

$$h_{mm} = S \times \frac{V^2}{127\, R_m}$$

in which

S = gauge in millimetres,
V = speed in kilometres per hour,
R = radius in metres,

from which the transverse inclination of the track is :

$$\operatorname{tg} \alpha = \frac{h}{S} = \frac{V^2}{127\ R}$$

1/10 may be taken as the maximum value of tg α (h = 150 mm = 6″ on the German Reichsbahn). On many railways, however, a higher value for tg α is admitted. Thus, on the Japanese Government Railways h = 115 mm. (4 1/2″) and tg α = 0.103 (4″), and on the South African Railways h = 127 mm. (5″) and tg α = 0.113 (4 7/16″).

Table 6 gives the maximum speeds of the locomotives of different gauges shown in table 5 : they have been calculated by MARIÉ's formula (11) for curves with transitions :

$$V^2 = \frac{\Delta\, pg \left[1 + \frac{P_2}{P_1}\right] R}{h_1 + h_2 \frac{P_2}{P_1} + \frac{an^2}{m^2 - an}} + g \operatorname{tg} \alpha\, R.$$

in which V = speed in metres per second,

Δ = allowed reduction of weight on outer wheels taken as 0.3 corresponding to a stability of 3.33.

P_1 = spring-borne weight

P_2 = Unsprung weight of the vehicle.

(11) MARIÉ, *Traité de stabilité du matériel des chemins de fer* (Treatise on the stability of railway vehicles), pp. 90 et seq.
The formula applies to the critical case of the turning over of a vehicle on its springs. The stability on the rails is studied later on.

For the locomotives under question $\frac{P_2}{P_1} = 0.25$ has been taken.

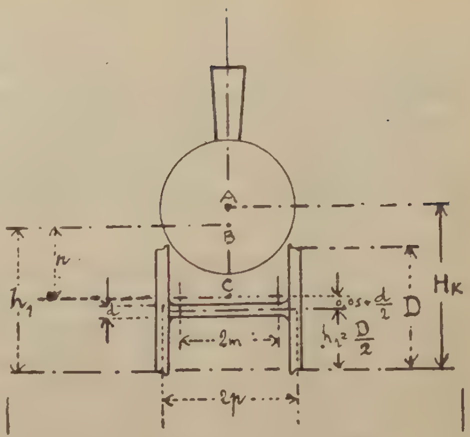
a = static deflection of the springs taken as 0.05 m. (2″) for all axles.

The other notations are shown in figure 2 and are :

h_1 = height of centre of gravity of spring-borne weight;

h_2 = height of centre of gravity of unsprung weight, taken as coinciding with the axle centre,

n = height of the centre of gravity of the sprung weight above the centre line about which the hunting oscillations of the vehicle take place. This centre is taken as being 50 mm. (2″) (2) above the upper generatrix of the axle journal.



Legend :
A = Centre line of boiler.
B = Centre of gravity of spring-borne load.
C = Centre of hunting oscillations of vehicle.

Fig. 2.

TABLE 5

Class of locomotive and maker.	Diameter of driving wheels, metres	Height of boiler centre line, metres	(12) h_1 metres	h_2 millim.	n metres	m millim.	p millim.	Maximum speed allowed (Technical Conventions), km./h. (*)	m. p. h.
1. Reichsbahn, class 02 . .	2.000	3.100	2.310	1 000	1.140	575	750	120	74.6
2. » » 44 . .	1.400	3.150	2.370	700	1.500	»	»	48	29.8
3. Japan, class C 53 . . .	1 750	2.530	2.110	875	1.110	400	560	103	64.0
4. South Africa, *Garratt*, Maffei	1.523	2.510	2.080	762	1.190	360	»	92	57.2
5. South Africa, Baldwin . .	1.524	2.540	2.120	762	1.230	»	»	93	57.8
6. » North British.	1.448	2.590	2.180	724	1.330	»	»	72	44.7
7. *Javanic*, Hanomag . . .	1.102	2.450	2.000	551	1.320	»	»	48	29.8
8. *Mallet*, Hanomag . . .	1.102	2.440	1.980	551	1.300	»	»	48	29.8
9. Express, Dutch Works .	1.600	2.300	1.790	800	860	»	»	109	67.7
10. Siam, Hanomag	1.371	2.560	2.150	686	1.340	330	530	82	50.9
11. N. E. of Brazil, Borsig . .	1.144	2 750	2.400	572	1.700	»	»	56	34.8
12. Jugoslavia, Borsig . . .	0.800	1.900	1.240	400	720	250	400	40	24.9

(12) The height of the centre of gravity of the spring-borne weight has been calculated for standard-gauge locomotives by Messrs. BAUMANN and JAEHN's formula $H_s = 1.368\ H_k - 1.935$, *Bulletin of the International Railway Congress*, December 1932, p. 2291 (English edition).

For the other locomotives it is obtained by the formula $H_s = 1.368\ H_k - 1.355$. We are obliged to Messrs. Borsig for this formula.

(*) HENSCHEL : Lokomotiv - Ingenieurs Taschenbuch, 1923 edition.

$2m$ = distance between the centres of the springs;

$2p$ = the distance between the wheel treads, taken as equal to the distance between rail centres;

g = acceleration due to gravity, 9.81 m. (32′ 2 1/4″).

Table 5 shows the chief dimensions of the locomotives being considered here.

From this data the radii of the curves (table 6) corresponding to the authorised speeds in the last column of table 5, and to the 1 in 10 superelevation of the track have been calculated (see table 6).

The speeds, calculated according to MARIÉ's formula, in miles per hour, are given in table 7.

There is no question of electric locomotives turning over on their springs as the centre of gravity of their spring-borne weight is much lower than that of steam locomotives; in addition they have outside axle boxes, so that the points of support on an axle are about twice as far apart. On the electric locomotives of the Rhætian Railway, for example, this

TABLE 6.

Locomotives and makers.	Authorised speed, m. p. h.	Corresponding radius, feet.
1. Reichsbahn, class 02 . .	74.6	3 717
2. » » 44 . .	29.8	597
3. Japan, class C 53 . . .	64.0	2 630
4. South Africa, *Garratt*, Maffei	57.2	2 180
5. South Africa, Baldwin . .	57.8	2 234
6. » North British.	44.7	1 580
7. *Javanic*, Hanomag . . .	29.8	597
8. *Mallet*, Hanomag	29.8	597
9. Express, Dutch Works . .	67.7	3 067
10. Siam, Hanomag	50.9	1 739
11. N. E. Brazil, Borsig . .	34.8	810
12. Jugoslavia, 760, Borsig .	24 9	414

TABLE 7. (13)

Radii in feet.

Locomotive number.	2 950	2 300	1 970	1 640	1 310	980	660	500	330	260
1	94.3	82.8	77.5	70.0	62.6	54.2	45.1	38.4	31.3	28.6
2	92.7	81.6	76.4	69.0	61.8	53.4	44.4	37.8	30.9	27.7
3	82.2	73.1	68.2	61.8	55.3	47.8	39.1	33.8	27.7	24.7
4	82.1	72.5	66.4	61.3	54.8	47.4	38.7	33.5	27.3	24.5
5	81.0	71.5	66.2	60.4	54.1	46.8	38.2	33.0	27.0	24.3
6	82.6	72.7	68.0	61.5	55.0	47.6	38.9	33.7	27.5	24.6
7	82.0	72.3	66.9	61.0	54.7	47.3	38.6	33.4	27.3	24.4
8	83.9	74.0	69.2	62.6	55.9	48.4	39.6	34.2	28 0	25.0
9	85.5	79 1	69.8	63.8	57.0	49.5	40.3	34.9	29.1	25.5
10	78.6	69.3	64.2	58.6	52.4	45.4	37.0	32.1	26.2	23.4
11	73.3	66.9	59.5	54.7	48.9	42.4	34.6	28.6	24.4	21.9
12	82.8	73.1	68.2	61.8	55.2	47.8	39.0	33.8	27.6	24.7

(13) Radii of curves requiring a speed reduction are shown between heavy lines.

distance is 4′ 5 1/16″ instead of 2′ 2″. On the South African locomotives it is 5′ 6″ instead of 2′ 4 3/8″.

The stability of the vehicles is much greater on the track than on their springs. We have calculated it, for the locomotives mentioned above, by the well known formula

$$n = \frac{p - e}{\left(\frac{V^2}{127.5\ R} - \operatorname{tg} \alpha\right) H}$$

in which the notation is the same as in the other formulæ. H is the height of the centre of gravity of the vehicle as a whole above the top of the rail and e = 11 cm. is the lateral displacement [14] of the centre of gravity under the influence of the centrifugal force.

We have calculated H for the standard-gauge locomotives by Baumann and Jaehn's formula, $H = 1.034\ H_k - 1.20$ and for the narrow-gauge locomotives by Borsig's formula, $H = 1.034\ H_k - 0.845$; tg α is taken as equal to 1/10.

Table 8 gives the corresponding information for the critical speeds.

Table 8.

Description of the locomotives. Builders.	Gauge.	Height of centre of gravity.	Radius of curve.	Authorised speed, m. p. h.	Stability.
1. Reichsbahn, class 02	4′ 8 1/2″	6′ 7 1/8″	1 640′	70.0	3.30
2. » » 44	»	6′ 9 1/8″	260′	27.7	3.41
3. Japan, class C 53	3′ 6″	5′ 9 7/16″	1 640′	61 8	4.16
4. South Africa, Garratt, Maffei . .	»	5′ 8 5/8″	1 310′	54.8	4.14
5. » Baldwin	»	5′ 9 13/16″	1 310′	54.1	4.33
6. » North British . . .	»	6′	660′	38 9	4.55
7. Javanic, Hanomag	»	5′ 6 9/16″	330′	27.3	5.03
8. Mallet, Hanomag	»	5′ 6 3/16″	330′	28.0	4 41
9. Express locom. Dutch Works, 1917 .	»	5′ 1/4″	1 640′	63.8	4.25
10. Siam, Hanomag	3′ 3 3/8″	5′ 10 7/8″	280′	75.4	4.27
11. N. E. Brazil, Borsig	»	6′ 6 3/4″	660′	34.6	5.69
12. Jugoslavia, Borsig	2′ 6″	3′ 8 1/16″	260′	24.7	3.77

The stability of electric locomotives and other stock on the track is not in question, as it is much greater than that of steam locomotives : only in the latter do we find the most unfavourable combination of high centre of gravity with the springs close together.

Table 7 shows that the speed need be reduced only for curves of less than 1 640 feet radius, even with the largest and heaviest locomotives. In the case of goods locomotives, and also passenger locomotives with relatively small driving wheels, the limiting curves are much

(14) *Verkehrstechnische Woche*, 1934, p. 312.

smaller as shown by the heavy lines in table 7.

The maximum permissible speed is determined by the design of the locomotive, and especially by the cylinder and wheel arrangement and the diameter of the driving wheels, and in general by § 102 of the Technical Conventions, but not by the track gauge. In the case of locomotives Nos. 1, 3, 4, 5, 6, 9, and 10 in Table 4, i.e. for actual passenger engines for the Cape and metre gauges, the maximum authorized speed is little different from that of the German 02 class engines, as shown by table 9.

The calculated high speeds shown in

TABLE 9.

Type of locomotive.	Gauge.	Authorised speed as a % of that of the 02 class locomotive, for curves of greater radius than those of table 6.
1. Reichsbahn, class 02	4′ 8 1/2″	100
2. Japan, class C 53	3′ 6″	85.9
4. South Africa, Garratt (Maffei)	»	76.7
5. » Baldwin	»	77.5
6. » North British	»	60.0
9. Express locom., Dutch Works, 1917 . .	»	91.8
10. Hanomag, Siam	3′ 3 3/8″	68.4

this table for narrow-gauge locomotives have been confirmed by actuel trial runs. For example, on a trial on the Javanese State Railways, the locomotive built by the Dutch Locomotive Works [15] hauled a train of 200 tons at 74.6 miles an hour. The highest speed of these engines is therefore that authorised in general working on the Reichsbahn.

The maximum authorized speed of the Japanese engines could be raised to 75 miles an hour, according to § 102 of the Technical Conventions, if they had 4 instead of 3 cylinders like the Javanese engines. In this case again, the speed limitation is due to the design of the locomotive and not at all to the gauge.

Table 10 gives the authorised speeds on the Japanese and South African Rail-

TABLE 10.

Radius of curve.	Authorised speed, in miles per hour.		
	Deutsche Reichsbahn.	Japanese Government Rys.	South African Rys.
3 280′	74 6	...	...
2 625′	68 4	...	55.0
1 970′	59.0	52.8	53.4
1 640′	52.8	49.7	49.7
1 310′	46.6	43.5	43.5
980′	40.4	37.3	39.1
660′	31.1	31.1	32.3
490′	24.9	...	28.0
330′	15.5	18.6	21.7

(15) *Organ für die Fortschritte des Eisenbahnwesens*, 1926, p. 242.

ways [16] compared with those on the main line of the Reichsbahn, as fixed by § 38-2*b* of the train working regulations of the 1st September 1933.

In the case of curves of small radius, on which the speed is limited by the stability of the vehicles, the speed limits are almost identical for all gauges.

IV. — The track.

The section and length of the rails obviously are independent of the gauge. Contrariwise, the length and section of the sleepers are dependent on the gauge to some extent. It might be assumed that, for equal length of sleepers, the load carried is better distributed on standard and broad-gauge track than on narrow gauge. This is not so in fact, as the load is not transmitted to the ballast by the whole of the sleeper, the middle of the sleeper transferring practically none.

According to ZIMMERMANN [17] the length of sleeper which transmits the load to the ballast is given by the formula :

$$L = \sqrt[4]{\frac{4\ EI}{Cb}},$$

in which

I is the moment of inertia of the cross section of the sleeper in cm^4,

E the modulus of elasticity in kgr. per cm^2,

C the ballast constant, in kgr. per cm^3,

b the width of the sleeper, in cm.

In the case of rectangular section wood sleepers, *h* deep and with E = 120 000 kgr. per cm^2, the equation becomes :

$$L = \sqrt[4]{\frac{4 \times 120\ 000 \times bh^3}{12\ Cb}} =$$

$$= \sqrt[4]{\frac{40\ 000\ h^3}{C}} = 14.14 \sqrt[4]{\frac{h^3}{C}}.$$

Table 11 gives the values of L on the different railways for ballast constants of 3 and 8.

TABLE 11.

—		Reichsbahn.	South Africa.	Siam.	Bosnia-Herzegovinia.
Gauge		4′ 8 1/2″	3′ 6″	3′ 3 3/8″	2′ 6″
Dimension of sleepers :					
Length 2*l*	cm.	270	213	190	160
Width *b*	»	26	25.4	20	20
Height *h*	»	16	12 7	15	13
L for C = 3	»	86	72	82	74
Distance, in the middle of the sleeper, between the areas transmitting the load to the ballast	cm.	98	69	26	12
L when C = 8	»	67	56	64	58
Distance between the areas in question	cm.	136	101	62	44

(16) *Bulletin of the International Railway Congress Association*, June 1932, pp. 1106/1107 (English edition).

(17) ZIMMERMANN : *Die Berechnung des Eisenbahnoberbaues* (The calculation of railway track), second edition, p. 178.

Using these data and applying ZIMMERMANN's method, we have calculated the pressures in the ballast and the maximum bending moments in the sleepers given here for the different railways, for a rail pressure P in metric tons and ballast constants of 3 and 8. The results are reproduced in table 12.

TABLE 12

—	Reichsbahn.	South Africa.	Siam.	Bosnia-Herzegovinia.
Gauge	4′ 8 1/2″	3′ 6″	3′ 33″	2′ 6″
Moment of resistance of sleeper	1 109	682	759	564
Volume of the sleeper	112 3	71.3	57.0	41.6
% of volume of Reichsbahn sleeper	100	63.5	50.3	37.0
When C = 3.				
Maximum pressure on the ballast, kgr./cm².	0.300 P	0.388 P	0.529 P	0.648 P
Maximum bending moment . kgr.×cm.	13 180 P	11 100 P	8 600 P	7 830 P
Maximum bending stress in the sleeper kgr./cm².	11.9 P	16.3 P	11.5 P	13.9 P
When C = 8.				
Maximum pressure on the ballast kgr./cm².	0.322 P	0.408 P	0.554 P	0.612 P
Maximum bending moment . kgr.×cm.	12 720 P	10 630 P	9 600 P	8 700 P
Maximum bending stress in the sleeper kgr./cm².	11.5 P	15.6 P	12.8 P	15.4 P

The pressure exerted on the ballast and the bending stress in the sleeper, *for equal rail pressures*, are greater as a rule in the case of narrow-gauge lines than in that of standard or broad-gauge track as table 12 indicates for sleepers actually in service.

This table also shows that when C = 3, i.e. with only poor ballast, the pressure on the ballast is much higher on the Siamese and Bosnia-Herzegovinian Railways than on the Reichsbahn, but that, against this, there is much less difference in the bending stresses. This proves that the section of the sleepers has not been properly selected; they are too narrow and at the same time relatively too deep.

On the South African Railways dimensions are more adequate as the stresses for C = 3 and C = 8 are in the same ratio as on the Reichsbahn. The pressure on the ballast, in fact, exceeds by 29 % and 27 %, and the bending stresses by 37 % and 36 %, the respective values on the Reichsbahn.

Table 13 gives the dimensions of 3′ 6″ (Cape) and metre-gauge sleepers in which stresses in the ballast and the bending stresses are about the same as for the Reichsbahn sleepers.

This table shows that, *for equal axle loads*, the volume of narrow-gauge sleepers is much less than that of standard gauge sleepers.

There is no relationship between the rail section and the gauge. The reason for nearly all narrow-gauge lines using

Table 13.

—	Reichsbahn 8′ 8 1/2 gauge.	3′ 6″ gauge lines.	Metre-gauge lines.
Sleepers :			
Width . . . . cm.	26	32.8	32
Depth . . . . »	16	12.7	12.5
Length . . . . »	270	213	210
Volume . . . . dm².	112 3	88.7	84.0
% of volume of Reichsbahn sleeper . . .	100	79	75
When C = 3.			
Pressure on the ballast . . . kgr./cm².	0.300 P	0 303 P	0.305 P
Bending stress . . . . »	11.9 P	12.9 P	12.9 P
When C = 8.			
Pressure on the ballast . . . »	0.322 P	0.316 P	0.335 P
Bending stress . . . . »	11.5 P	12.2 P	13 4 P

lighter rails than are used on European and American railways is that the narrow gauge lines are not so heavily equipped on the whole.

It should be noted, however, that the following rails were in use in 1927 on the main lines of the Union of South Africa [18] :

From 20 to 20 1/4 lb. per yard on	1 050	miles or	8.4	% of the total mileage.
» 45 » 46 » »	1 745	» »	14.0	» » »
» 50 » 52 » »	100	» »	0.8	» » »
» 59 » 61 » »	5 592	» »	45.0	» » »
» 75 » 85 » »	3 912	» »	31.4	» » »
Of 100 lb. per yard	49	» »	0.4	» » »
Total . . .	12 448	miles or	100	% of the total mileage.

The rails are laid as a rule with 2 100 sleepers per mile. Rails weighing 85 lb. per yard, used on all important main lines, are 5″ high with a width of head of 2 11/16″.

On the main lines run over by locomotives with 22-ton axle loads, these rails are renewed, when relaying, by heavier rails weighing 100 lb. per yard.

Very heavy rails are also used on other 3′ 6″ gauge lines. Thus, the Javanese State Railways, on which speeds of 62 m.p.h. are allowed, use rails weighing 83 3/4 lb. per yard, laid on 2 480 sleepers per mile [19], and in Japan many of the lines are laid on rails weighing 100 lb. per yard.

Generally speaking, many narrow-gauge railways on which the traffic has developed have laid heavier rails than many a standard or broad-gauge line, even with a relatively heavy traffic.

(18) *The Railway Gazette*, Special number, 21 November 1927, p. 17.

(19) *Organ für die Fortschritte des Eisenbahnwesens*, 1926, p. 341.

V. — Formation.

The formation of narrow-gauge lines differs from that of standard or broad-gauge lines by :

1) smaller radii of curves which, however, do not largely increase the rolling resistance;

2) narrower formation.

These are the only two factors which may possibly lead to a reduction in the cost of construction as they *depend directly on the gauge.*

The maximum permissible gradients bear no direct relation to the gauge. The fact that steeper gradients are often found on narrow-gauge railways, especially in Europe, is due, as already noted,

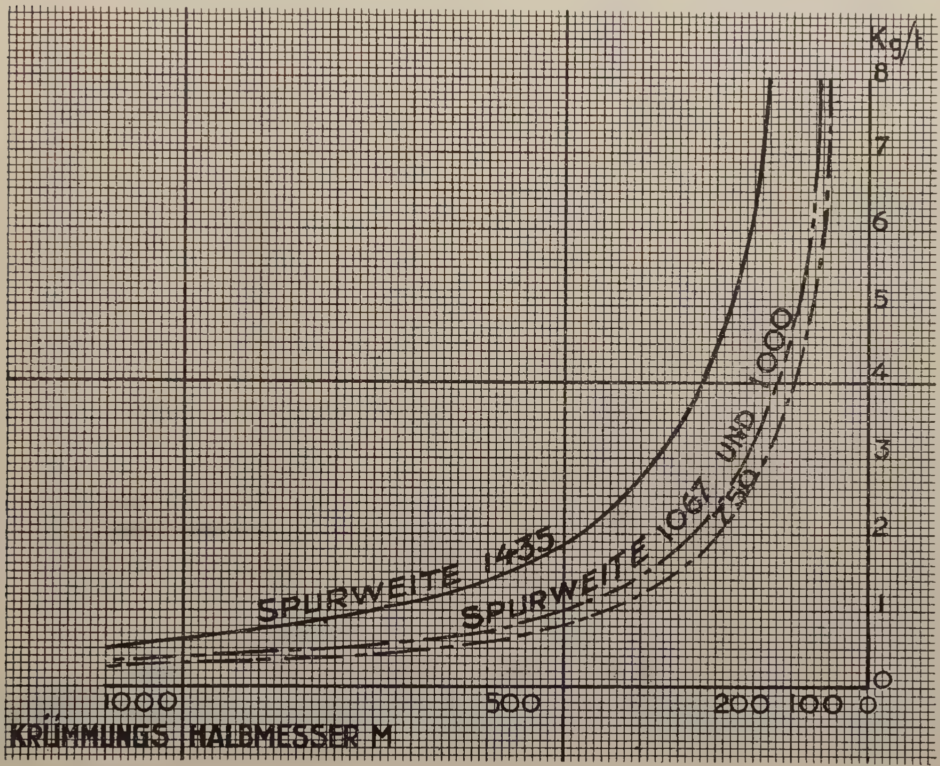


Fig. 3.

Note: Spurweite = track gauge. — Krümmungshalbmesser = radius of curve.

to the fact that they are secondary or local lines, and not main lines. The ruling gradient adopted ought to depend upon the estimated traffic.

If the gauge is to be taken into account when determining the ruling gradient, the gradient on narrow-gauge lines, all other factors being equal, should rather be easier, as the cost of the rolling stock, and especially the locomotives, for such railways per unit of weight or per unit of tractive effort, is higher as a rule. The

difference is so small, however, as to be negligible.

The resistance due to curves decreases as the gauge becomes smaller. Whilst this resistance has been carefully investigated many times for standard-gauge lines, and whereas there are many formulæ for calculating it, the case of the narrow-gauge line is quite different.

Figure 3 shows the rolling resistance for various radii of curves: for standard-gauge lines it has been calculated by RÖCKL's formula $w = \frac{400}{R\text{-}55}$; for the other gauges, by HAARMANN's formulæ: $w = \frac{400}{R\text{-}20}$ for the 3′ 6″ and metre-gauge lines, and $w = \frac{350}{R\text{-}10}$ for the 2′ 6″ gauge lines.

At low speed, the vehicles can run through very sharp curves. Without mentioning urban lines, on which curves as sharp as 98′ radius are found, lines carrying fast trains such as the Paris Metropolitan have curves of 164′ radius [20].

Still smaller radii are found, it is true, on narrow-gauge lines. It should be noted, though, that whilst curves of 623′ (*), 738′ (**), and even 476′ (***) radius were allowed on old main-line railways, nothing under 984′ is now permitted on lines recently built. On the other hand, on the 3′ 6″ and metre-gauge lines a radius of 328′ may be taken as the maximum, although radii of 300′ are frequently found on the mountain sections of the South African Railways.

The minimum radius of curve is not only determined by the rolling resistance, but chiefly and especially by the necessity for maintaining a certain speed, and on the main lines this radius cannot be reduced very much on account of the fast trains run.

VI. — Construction costs.

The narrower formation saves earthwork and cheapens the structures. In the case of heavy earthwork the saving becomes considerable; however, it diminishes proportionally as the total volume increases, the earth slope is independent of the width of formation, and in heavy work this part of the volume is preponderating.

Table 14 gives examples of the reduction in volume per yard of line of the formation on the South African Railways (width of bed 16′) and on the metre-gauge Rhætian Railway (width of bed 12′ 6″) comparatively with the single-track lines of the Swiss Federal Railways (width of bed 17′ 4 5/8″).

The greater economies in the cost of construction of narrow-gauge lines is due to the fact that sharper curves can be used. Such economies cannot be evaluated however with any accuracy for any particular railway, as to do so would mean careful calculations with two different locations. Now, such investigations are not often made as the gauge is usually the first thing decided for any railway.

Some information is nonetheless available for a certain number of railways with different gauges having similar working conditions, and for which the

(20) This curve is run over at 15 1/2 miles an hour. The vehicles used have 8′ 10 1/4″ wheel base bogies, and wheels 2′ 9 1/2″ in diameter. Curves of 100′ radius are also found in loops in many terminal stations, but are not run over by the regular trains.

(*) On the Semmering line.

(**) On the Arlberg line.

(***) On the Trans-Caucasian 5′ gauge railway (U. S. S. R.).

TABLE 14.

Height of fill.	Volume of fill.			Reduction in volume on			
	Swiss Federal Railways.	South African Railways.	Rhætian Railway.	South African Railways.		Rhætian Railway.	
m.	m^3	m^3	m^3	m^3	$^0/_{00}$	m^3	$^0/_{00}$
1	6 80	6.37	5.30	0.43	6.33	1.5	22.0
5	64.00	61.35	56.50	2.15	3.36	7.5	11.0
10	203.00	198.70	188.00	4.30	2.12	15.0	7.4
15	417.00	410.55	394.50	6.45	1.55	22.5	5.4
20	706.00	697.40	676.00	8 60	1.22	30.0	4.2

costs of the permanent way and rolling stock are given separately in the returns.

Amongst such railways the Australian System should be mentioned to begin with, as it is a jumble of 5′ 3″, 4′ 8 1/2″ and 3′ 6″ gauge lines.

Table 15 gives particulars of the cost of the fixed installations of the different Australian railways in sterling.

The cost per mile of the broad-gauge lines in South Australia is not only increased by the gauge, but also by the

TABLE 15.

Railway.	Gauge.	Length of system. Miles.	Cost per mile. £
South Australian Govt. Rys. broad gauge .	5′ 3″	1 451	9 450
Trans-Australian Govt. Rys.	4′ 8 1/2″	1 052	6 515
Central Australia Ry.	3′ 6″	771	5 573
South Australian Govt. Rys.	„	1 078	4 600
Queensland Govt. Rys.	„	6 430	4 451

55 miles of double and quadruple-track lines in and about Adelaide.

In Java, were the 3′ 6″ gauge is the standard on the State Railways, there are some 163 miles of 4′ 8 1/2″ operated by the Dutch East Indies Company. This system lies in a flatter part of the country than most of the State lines. The annual accounts of this Company unfortunately do not contain any details on the original capital cost (including rolling stock, electrical equipment, etc.). As the returns give, however, the locomotive and rolling stock figures, the cost of the fixed installations can be deduced fairly accurately as is seen from table 16. (Position as at the 1st January, 1929).

This table shows that the Java State lines were as nearly well equipped with rolling stock as those of the East Indies

TABLE 16.

—	Dutch East Indies Company.		State Rys.
Gauge	4' 8 1/2"	3' 6"	3' 6" [21]
Mileage of system	162	374	1 728
Capital cost per mile . . . £	23 480	14 420	21 500
i.e. Permanent way . . . »	17 100	12 260	...
i.e. Rolling stock and stores . . . »	6 380	2 160	...
Rolling stock per mile :			
Locomotives . . . units	0.438	0.300	0.357
Passenger carriages . . . »	0.757	0.612	0.81
Goods wagons . . . »	11.16	4.83	8.47

Company, the former owning 18 % less locomotives, 6 % more passenger coaches, and 24 % less goods wagons.

This made it possible to compare with a sufficient degree of exactness the cost of standard and 3′ 6″ gauge permanent way.

The saving effected by building a main line of 3′ 6″ or metre-gauge compared with standard gauge may be calculated as follows :

1. **Track and ballast.** — As we have already pointed out, the sleepers alone have to be considered, as the rails depend on the weight of the stock and to some extent on the speed, and not on the gauge.

Comparing the Reichsbahn 045 track with that of the South African Railways laid with 85 lb. per yard rails, we find that the weight per mile of the metal sleepers on the former is 349 200 lb., whereas it is 312 200 lb. on the latter, the weight saving being thus 10.6 %. In the case of wooden sleepers the saving is less easily ascertainable, their size depending to some extent on the kind of timber available locally.

There is also a saving in the ballast. Comparing the tracks mentioned above the top surface of the ballast is 10′ 10″ wide on the Reichsbahn, and 8′ in South Africa. Taking the depth of ballast under the rails as 1 foot, the volume per mile is 2 492 cu. yards for the standard gauge, and 1 934 cu. yards for the 3′ 6″ gauge or a saving of 22 % in the case of the latter [22].

A slight saving is also made when laying the track but the amount cannot be stated more or less accurately.

2. **Permanent way.** — As we have already seen, the expenditure on permanent way and fixed installations varies very largely as between railways. Generally speaking, it may be stated that the cost of narrow-gauge permanent way is much less in mountainous country if

[21] This system included at that date 132 miles of double or multiple-track lines and 20 miles of electrified lines.

[22] The data relating to the South African Railways are taken from *The Railway Gazette*, Special number of the 21st November, 1927.

small-radius curves are used. In flat country, the saving on the track itself is the largest item. Table 15 shows, moreover, that the Australian Federal Railways' 3′ 6″ gauge lines only cost 14.3 % less than the standard gauge.

But, if the Rhætian Railway be compared with the Toggenburg line, both in Switzerland, the formation of the former costs 2.35 % less than the latter, although it certainly runs through more difficult country.

In South Africa the savings resulting from the use of the narrow gauge were so large that a 60-mile length of standard-gauge track has been converted to 3′ 6″; most of the South African lines are located in hilly country.

The South African Railways, the cradle of the 3′ 6″ gauge, can be used as the model [23] for the construction of 3′ 6″ and metre-gauge *main lines*.

VII. — Working costs.

Any satisfactory comparison between the working costs of railways of different gauges is very difficult to get out as the working conditions are so different.

The narrow-gauge lines, even when they have the features of main lines, nearly always have sharper curves and also much steeper gradients. Then too their traffic is smaller as a rule, and the operating costs per net ton-mile and per passenger-mile are of course higher. There are very few railways of different gauges, which not only were built under the same conditions but are also operated on almost the same lines, which would thus afford a satisfactory comparison as regards working costs.

A. — South Indian Railway.

This Company has a broad-gauge (5′ 6″) main line with four branches, of a total length of 599 miles, and 1 829 miles of narrow gauge. These can be compared with the 2′ 6″ gauge lines of the Bengal Nagpur Railway which have the same gradients and section, as is shown in table 17.

TABLE 17.

—	South Indian.		Bengal Nagpur.
	5′ 6″	3′ 3 3/8″	2′ 6″ gauge.
Level sections or gradients of less than 1 in 300, % of total length	64.6	63.8	50.6
Gradients of 1 in 201 to 1 in 300	7.2	7.6	5 9
» » 1 in 101 to 1 in 200	17.8	20.2	22.1
» » 1 in 81 to 1 in 100	7.8	4.6	16.6
» » 1 in 51 to 1 in 80	2.6	2.5	4.8
» » 1 in 50 and steeper	...	1.3	...
Smallest radius of curve	800′	500′	410′

(23) As can the Japanese and Javanese, the former especially.

Table 18 gives details on different points which may affect the expenditure; these are taken from the 1932-33 Annual Report of the Indian Railways and the September 1934 Newman's Indian Bradshaw.

TABLE 18.

—	South-Indian.		Bengal-Nagpur.
	5′ 6″ gauge.	3′ 3.3/8″	2′ 6″ gauge.
Total length of lines . . . . . . miles.	599	1 829	926
Total net ton-miles (24) . . . thousands.	161 258	263 665	40 422
Total gross ton-miles (25) . . do.	457 469	722 343	136 297
Net ton-miles per mile of line	269 000	143 750	43 700
Gross lb. per net ton (26)	6 360	6 140	7 550
Total passenger-miles . . . . thousands.	298 773	1 063 301	78 285
Total gross ton-miles in passenger service . . . . thousands.	751 303	1 228 774	166 994
Passenger-miles per mile of line	497 127	580 649	84 510
Gross lb. of load per passenger mile (27) lb.	5 624	2 585	4 674
Average daily number of passenger and mixed trains	10.66	10.49	3 86
Number of express trains included in previous item	2.12	1.18	...
Average overall speed of all passenger and mixed trains . . . . m.p.h.	17.4	16.2	12 7
Average overall speed of express trains m.p.h.	28.4	25.3	...

It will be seen from this table that the goods traffic on the broad-gauge lines of the South Indian Railway is nearly twice that of the metre-gauge lines. On the other hand, the passenger traffic is higher on the latter by 17 %.

In the matter of goods traffic, the gross load corresponding to 1 ton of net weight on metre-gauge lines is only 4 % less than with standard gauge.

But the difference between the net load per passenger-mile is much greater for the different gauges, the reason being that on the metre-gauge lines the net load per passenger-mile only represents 46 % of that for the broad-gauge lines (28).

(24) By « ton » is to be understood « English ton » (2 240 lb.).

(25) The gross ton-miles here also include the locomotives themselves.

(26) On the Reichsbahn this number in 1928 was 5 890 lb.

(27) On the Reichsbahn this number in 1928 was 7 230 lb.

(28) This great difference in the gross weight per passenger is explained by the fact that the tare weight per seat on the metre-gauge lines is about 2 1/2 times less than on the broad-gauge lines.

As already pointed out, the rolling resistance decreases as the gauge increases, and this is confirmed by the coal consumption figures on lines of different gauges, as is shown in table 19.

This table shows that the coal consumption per gross ton-mile is almost the same on broad, standard, and Cape or metre gauges. Against this, it is a little lower in passenger service on the 3′ 6″ and metre-gauge lines. On 2′ 6″ gauge lines it is double that of standard or broad-gauge lines.

Table 20 gives the various expenditures

TABLE 19.

—	Gauges.		
	5′ 6″	3′ 3 3/8″	2′ 6″
Coal consumption per 1 000 gross ton-miles :			
Passenger services . . . . lb.	165.9	188.4	373 5
% of the consumption on 5′ 6″ gauge . .	100	113.8	225.0
Goods services . . . . lb.	123.5	122.0	344.1
% of the consumption on 5′ 6″ gauge . .	100	98.8	276
Coal per 1 000 passenger-miles . . . . lb.	415.0	217	796
Coal per 1 000 net ton-miles	350	334	1 146

TABLE 20.

—	South Indian.		Bengal-Nagpur.
	5′ 6″ gauge.	Metre gauge.	2′ 6″ gauge.
Maintenance and renewal of the track.			
Total expenditure . . . . . . Rm. (29).	425 000	1 234 000	598 500
Per mile of line . . . . Rm.	709	621	577
Per mile of track . . . . »	581	509	492
Maintenance and renewal of locomotives.			
Total expenditure . . . . Rm.	745 000	1 730 000	467 000
Per 1 000 locomotives-miles . . . . . »	168	179	215
Per 1 million of gross ton-miles . . »	617	887	1 540
Per 1 million of passenger miles . . »	1 548	1 023	3 215
Per 1 million of net ton-miles . . »	17 521	2 430	5 190
Maintenance and renewal of rolling stock :			
Total expenditure . . . . Rm.	302 000	862 000	339 000
Per 1 million of axle-miles . . . . »	2 192	2 135	3 730
Per 1 million of gross ton-miles . . »	250	442	1 118

(29) The figures of the Annual Report are converted at the rate of 1 Rupee = 1.12 Rm.

which depend on the gauge. This table is prepared from data given in the Report of the Indian Railways for 1932-33.

This table shows that the expenditure per locomotive-mile per vehicle axle-mile for maintenance and renewal are somewhat less on metre-gauge than on broad-gauge lines. They are also less per passenger-mile, but 38 % higher in goods working.

The corresponding figures for 2′ 6″ gauge are much higher than for broad and metre-gauge lines.

B. — Rhætian Railway and Lötschberg Railway.

These Swiss Companies, the first of which has 171 miles of metre-gauge line and the second, excluding the Munster-Langau line, 65 miles of standard-gauge, are both electrified.

We will compare the operating costs of these lines, although their gradient sections differ as shown in table 21.

TABLE 21.

—	Lötschberg.	Rhætian.
Gauge	4′ 8 1/2″	3′ 3 3/8″
Total length . . . miles	65	171
As a % of total length :		
Level section	17.5	18.2
Gradients up to 1 in 200	15.6	8.8
» from 1 in 100 to 1 in 200	11.8	18.3
» from 1 in 100 to 1 in 66	14.5	9.4
» from 1 in 66 to 1 in 50	4.5	11.6
» from 1 in 50 to 1 in 40	20.3	10.0
» from 1 in 40 to 1 in 33	15.8	4.7
» exceeding 1 in 33	...	19.0
Steepest gradient allowed	1 in 37	1 in 28.5 [30]
Average gradient	1 in 63	1 in 50.2
Smallest radius of curve	590′	328′

Table 22 gives particulars of the operating results and expenditure from the returns for 1932 and the 1931/1932 Winter timetable.

[30] Exceptionally 1 in 22 on the Küblis-Davos section, 17.3 miles long.

TABLE 22.

—	Lötschberg.	Rhætian.
Average number of passenger trains per day* .	22 2	21.0
Average train speed . . . . m.p.h.	21.3	17.0
Maximum booked speed* . . . . . »	39.1	21.4
Per mile operated :		
Passenger miles	366 000	161 380
Net ton-miles of all kinds	347 000	35 700
Total length of track of all kinds . .miles.	119	209
Expenditure per track-mile for maintenance and renewal of permanent way . . Rm.	2 232	1 268
Power consumption in kw./h. per :		
1 000 locomotive-miles	20 920	12 875
1 000 gross ton-miles	75.00	97.60
Consumption of lubricants :		
Per 1 000 locomotive-miles . . . . .lb.	90.2	104.6
Per 1 000 gross ton-miles . . . . . .lb.	0.335	0.793
Locomotive maintenance and renewal costs per :		
1 000 locomotive-miles . . . . Rm.	707	264
1 000 gross ton-miles . . . . »	1.93	1.99
Maintenance and renewal costs for passenger carriages and rail motor cars per :		
1 000 axle-miles . . . . Rm. (31).	30.0	18.50
1 000 gross ton-miles in passenger service (32) . . . . Rm.	4.40	3.58
Maintenance and renewal costs of goods wagons, brake vans, postal vans and service vehicles, per :		
1 000 axle-miles . . . . Rm.	27.80	21.10
1 000 gross ton-miles in goods service . »	1.63	4.42

VIII. — Operating results on some narrow-gauge main-line railways.

The different operating results of narrow-gauge railways we have examined show that such lines are able to provide services almost as fast, comfortable and efficient, as standard or broad-gauge lines.

This statement can be confirmed by the operating results of some of the most important 3′ 6″ and other narrow-gauge lines.

(31) The Rhætian Railway owns no rail motor cars, and this explains the lower cost of repairs and renewals of passenger stock on this line.

(32) The gross ton-miles to which the expenditure is related do not exclude the locomotive ton-miles although they include those related to rail motor cars.

1. Japanese Government Railways. — We will reproduce the information contained in the Annual Reports covering the period from April 1927 to the 31st March 1930, i.e. that before the crisis, when the traffic was heaviest.

Although these railways are divided amongst the four main islands, they must be considered as a single system as the islands are connected together by ferry-boats.

As the 31st March 1930, the Japanese Government Railways had a mileage of 8 707 miles, 1332 or 15.5 % of which were double or multiple-track lines. In addition at the same period 609 miles were under construction and 2 401 miles were authorised (33).

Each mile of *line* represented, at that time, 1.117 miles of *running track* and 0.482 mile of *other track (sidings, etc.)* (34).

The capital invested was £ 23 800 per mile on the 31st March 1930.

The average traffic on the Japanese Government Railways is very interesting, not only in comparison with other 3′ 6″ gauge lines, but also with the European railways, as table 23 shows.

If however we wish to get a better idea of the greatest possible traffic capacity of 3′ 6″ gauge-lines, the figures for the Tokyo division must be considered. During the 1929/30 working the average traffic in this division of 1 788 km. (1 111 miles) was per mile 4 230 000

TABLE 23

—	1929-30	1928-29	1927-28
Average length operated . . . . . .miles.	8 637	8 407	8 146
Total number of :			
Passenger-miles . . . . . . .millions.	13 260	13 409	12 440
Gross ton-miles . . . . »	7 560	7 680	7 490
Per mile operated :			
Passenger-miles	1 533 000	1 592 000	1 532 000
Net ton-miles	875 000	917 000	920 000
Daily number of train-miles per mile of line operated :			
Total	21.71	21.33	20.91
Including passenger trains	14.68	14.15	13.57
Including goods trains (35)	7.03	7.18	7.34
Average train composition :			
Passenger trains . . . . .vehicles.	6.7	7.1	7.2
Goods trains . . . . »	35.5	35.7	34.8

(33) 1 004 miles of these have been put into service since the 31st March 1934, so that at that date the mileage was 9 779 (*Railway Gazette*, 2nd half 1934, p. 518).

(34) The corresponding figures at the 31st December 1929 for the Reichsbahn were 1.448 miles of running track and 0.822 mile of other track.

(35) The corresponding figures for the Reichsbahn for 1929 were 875 000 passenger-miles per mile, 1 398 000 net ton-miles per mile; 21.5 passenger trains, and 15.83 goods trains daily.

passenger-miles and 1 344 000 net train-miles (36).

The number of passenger trains on the different lines is also very high. During the 1932 Summer, for example, the average number of trains between Tokio and Kobe each day was 54.6, 19.27 being express and fast, averaging 32.6 miles an hour. Two pairs of these trains run at an average speed of 41.9 miles *over the whole distance.* This line includes 37 miles of mountain section with 1 in 40 gradients. The average speed of all other trains between Tokyo and Kobe was 25.5 miles an hour and this bears comparison with the best European railways (37).

Now, such dense traffic and high speed are found not only on the Japanese main lines but also far from Tokyo, as for example on the Hokkaido system (to the North of the main Island) which consists of 1 681 miles of line, 133 miles being double-tracked. The average number of passenger trains run daily on this system is 12.2 at an average speed of 18.9 miles an hour, 1.32 of which are expresses running at an average speed of 22.9 miles an hour.

Finally it should be noted that the Japanese rolling stock is used most intensively and the figures are world records as will be seen in table 24 which, for comparison, gives the same figures for the Reichsbahn.

2. **South African Railways.** — As already stated (38) the largest system of 3′ 6″ gauge lines is in South Africa; the total length in round figures is 18 000 miles. The greatest continuous 3′ 6″ gauge line, 3 617 miles long, is also found there, namely between Capetown and Lobito (39). It will be 4 100 miles long, and run between Capetown and Pointe Noire (French Congo), when the 500-mile section between Port Francqui and Léopoldville is completed, and a ferry boat service is established over the River Congo to link up the Belgian and French railway systems.

We will mainly quote hereafter the operating results of the South African Railways, whose equipment is of a high standard, and which carry a relatively dense traffic.

We have already seen the high standard of the permanent way on these railways. The lines are nearly all single track; double and multiple-track lines represent only 1.3 % of the total mileage. The cost per mile of the system is relatively low; at the end of 1928-29 year's working it was only £ 7 000.

The rolling stock is up-to-date and highly efficient, as shown by several examples in tables 3 and 4.

(36) Using Mr. Blum's figures in Table III, *Archiv für Eisenbahnwesen 1933,* pp. 913 to 940, the most intense goods traffic on the Reichsbahn was in 1927 and 1928 on the following lines:

Munster-Hamburg	length	179	miles,	11 220 000 net ton-miles per mile.
Hanover-Lehrte	»	120	»	15 070 000 » » » »
Soest-Nordhausen	»	145	»	9 000 000 » » » »
Hanover-Göttingen	»	93	»	7 330 000 » » » »

(37) The same year the average number of passenger trains per day on the Swiss Federal Railways was 29, with an average speed of 24.35 miles an hour.

(38) Table 1.

(39) In the Portuguese Angola Colony, on the Atlantic.

TABEL 24.

—	Japanese Government. 1929-30.	Reichsbahn. 1929.
Passenger coaches :		
Total stock	11 495	63 641
Total number of seats	661 385	3 574 825
Seats provided :		
per *vehicle*	57.5	55.8
per *mile* of line	76.6	106 0
Total miles run :		
vehicles . . . 1 000 miles.	502 700	2 380 000
seats provided . . . »	28 360 000	124 400 000
Average vehicle mileage	44 000	37 600
Total passenger-miles	13 260 000	29 260 000
Annual total of passenger-miles :		
per coach	1 154 000	459 500
per seat provided	20 000	8 300
Average number of passengers :		
per coach	26.4	12.2
per seat provided	0.459	0.226
Goods wagons :		
Total stock.	67 434	681 738
Total loading capacity . . . tons.	879 274	10 797 920
Average loading capacity per wagon . . . lb.	28 750	34 945
Average loading capacity per mile of track . . tons.	63 2	201 0
Total miles run :		
wagons . . . 1 000 miles.	1 268 000	6 375 000
tonnage . . . »	16 300 000	99 100 000
Annual mileage per wagon	18 815	9 283
Total net ton-miles . . . 1 000.	7 565 000	42 150 000
Net ton-miles per year :		
per wagon	112 400	61 200
per ton of tonnage	8 620	3 690
Average load :		
per wagon . . . lb.	13 440	14 820
per ton of tonnage . . . »	1 020	953

Table 25, the figures of which relate to 1928-29 gives a good idea of the total rolling stock of these railways.

The rolling stock was slightly increased in the subsequent years, but as the traffic fell off it was used less efficiently.

The Annual Reports of the South African Railways do not contain any precise information on the passenger miles run; they can only be calculated approximately from the total passenger receipts and rates, the average amount of which moreover is not shown in the returns.

Table 26 gives the operating results for the 1928-29 year's working.

The traffic varies considerably from one line to another. The heaviest traffic is found on the 190 miles long Natal

TABLE 25

—	Total.	Per mile of track (12 600 miles).	Per unit.
Number of locomotives	2 185	0.106	...
Average weight of locomotives . . . tons.	...	...	67.3
Tractive effort . . . . lb.	58 550 000	4 580	26 800
Number of goods wagons	32 686	2.59	...
Number of wagon-axles	95 093	7.45	2.91
Tonnage of wagons	715 000	56.7	21.85
Number of passenger coaches	3 633	0 288	...
Number of passenger-coach-axles	14 362	1.14	...

TABLE 26.

—	Total.	Per mile of track.
Passenger-miles	1 118 500 000	55 200
Net ton-miles	4 460 000 000	352 000
Coal ton-miles (included in previous item) .	1 359 000 000	160 500
Train-miles per annum	49 232 000	3 912
Train-miles per diem	136 550	10 83
including :		
Passenger train-miles per annum	37 900	3.02
Mixed-train-miles per annum	14 500	1.16
Goods-train-miles per annum	84 000	6.65

line, between Ladysmith and Durban, which carries the whole of the export coal traffic to the important port of Durban. This line is electrified on 120 miles; it has 1 in 65 maximum gradients in the Durban direction and 1 in 50 in the inland direction. The smallest radius of the curves in flat country is 400′, but such curves are unusual, the normal minimum being 550′.

Part of the line is double track; on some sections, in order to relieve the main line, the original line is still used in spite of its 1 in 30 gradients and 300′ radius curves.

The railway is equipped to handle 26 700 gross tons per day towards the coast. The actual average traffic is very heavy; during the best years before the crisis, the following tonnages of coal were conveyed — and shipped at Durban — over the line from Ladysmith :

1926-27	working year :	2 740 000 tons;
1927-28	»	2 410 000 »
1928-29	»	2 320 000 »
1929-30	»	2 460 000 »
1930-31	»	1 735 000 »

As in addition to coal, large quantities of other merchandise are exported and imported via Durban, during the best years this line handled a goods traffic of 4 000 000 net tons.

The South African Railways have also handled quite exceptionally heavy loads, such as for example a stator weighing 76 tons, measuring 12 1/2′ × 15 3/4′ × 6 1/4′. Such loads are only occasionally dealt with, even on European railways.

The passenger traffic is much more like that on the American railways than on the European; it is relatively speaking light [40] but, excepting the suburban traffic round the large cities, is carried very long distances. There are a number of fast train services, which were accelerated last year, and it is expected will be further speeded up this year [41]. Such trains, however, run only 2 or 3 times a week.

Generally speaking, the average speed of all passenger trains shown in the May 1932 timetable was 19 miles an hour.

Table 27 gives information on the runs and journey times of some of the through express trains.

Table 27.

—	Distance.	1932		1935	
	Miles.	Time spent.	Average speed. M. p. h.	Time spent.	Average speed. M. p. h.
Johannesburg-Capetown	956	28 h. 27′	33 6	20 h. 43′	46.1
Capetown-Bulowayo	1 360	48 h. 20′	28.1	42 h. 58′	31.8
De Aar-Walvis Bay	1 134	56 h. 38′	20.0	55 h. 35′	20.5
Johannesburg-Durban	483	18 h. 45′	26.3	18 h. 0′	27.5
Capetown-Port Elisabeth	673	37 h. 57′	17.8	28 h. 54′	23.3

(40) In 1929, the passenger traffic in the United States, on class 1 railways, was only 128 300 passenger-miles per mile, and it has fallen off 50 % since.

(41) *Railway Gazette*, First half-year volume, 1935, p. 685.

Such overall speeds should be considered as very high, as in Europe and America long-distance trains do not run much faster [42].

3. **Javanese State Railways.** — In order to get an idea of the activity of these Railways, the operating results for the year 1928, that in which the traffic reached its maximum before the crisis, will be quoted.

At the end of that year, the length of the system was 1 728 miles, 122 miles or 7.1 % of which was double-tracked.

The rolling stock consisted of 621 locomotives, 1 272 passenger coaches, and 15 048 goods wagons, luggage vans and service vehicles of various kinds. This stock corresponds to 0.357 locomotive, 0.81 passenger coach and 8.47 goods wagons and other vehicles per mile of line operated.

In 1928, the average cost of the Javanese Railways amounted to £ 21 500 per mile.

For the same year, the goods traffic was 255 000 net ton-miles per mile, and the passenger traffic 486 414 passenger-miles per mile worked.

The first-class lines, 1 110 miles long, were served by an average of 18.65 trains daily, 5.27 being express. The average speed of all passenger trains was 19.5 miles an hour, and that of the expresses 28 miles an hour. The average speed of the fast trains between Batavia and Soerabaja [43], which crosses almost the whole Island in 13 h. 42 m. was 37.6 miles an hour. This was reduced to 11 h. 55 m. in the November 1934 timetable, which gives an average speed of 42.9 miles an hour. The number of express trains as shown in this timetable has been markedly increased [44].

4. **Bosnia-Herzegovinian Railways.** — These 2′ 6″ gauge State Railways are 1 184 miles long. A number of private railways are connected with them, the total mileage over which passenger trains are run, thus being 1 587 (*).

As we pointed out on page 413, this separate system runs through very mountainous country and the narrow gauge has made it possible to use curves of as small a radius as 328′ without disadvantage.

Only 23.7 % of all the State lines are on the level, and on 22.7 % there are gradients steeper than 1 in 100.

On the main line between Serajevo and Doubrovnik, there are a number of rack sections, 11.2 miles in all, with gradients as steep as 1 in 16.

The capacity of these railways is, however, very great. The rolling stock owned by the State at the end of 1933 was 0.5 locomotive per mile, with an average of 3.81 driving axles, 0.76 vehicles for passenger trains (carriages, post office vans, and parcels brake vans) with an average of 3.26 pairs of wheels, 8.93 goods wagons of all kinds with an average of 3.43 pairs of wheels, the average axle load being 8 160 lb. (**).

---

(42) The « Continental Limited » between Montreal and Vancouver (2 929 miles) runs at an overall speed of 33.6 miles an hour; that of the « Orient Express », between Paris and Constantinople (1 928 miles), is 32.9 miles an hour.

(43) Distance 512 miles. The maximum altitude reached is 2 926′.

(44) *Zeitung der Mitteleuropäischen Eisenbahnen*, 1934, p. 833.

(*) From the Jugoslav official timetables.

(**) From the *Jugoslav statistical railway returns* for 1933.

In 1932 and 1933, the goods traffic was almost as heavy on the 2′ 6″ gauge lines as on the other lines of the Jugoslav system, as is shown in table 28 which also gives other information with regard to their operating results.

TABLE 28.

	Standard-gauge lines.		2′ 6″ gauge lines.	
	1932	1933	1932	1933
Total mileage	4 371	4 375	1 184	1 185
Total number of trains per day and per mile	20.78	20.79	22.88	21.43
Including passenger and mixed trains	12.89	13.44	9.90	9.27
Net ton-miles per mile	336 000	335 000	283 000	301 000
Passenger-miles per mile	216 403	204 743	128 704	120 957
Gross ton-miles per mile :				
Passenger and mixed trains	605 000	619 000	241 000	225 500
Goods and departmental trains	855 000	837 000	623 000	625 000
Gross weight :				
per passenger .lb.	6 261	6 769	4 189	4 178
per ton of net weight .lb.	5 515	5 412	4 770	4 500
Coal consumption per 1 000 gross ton-miles .lb.	382	372	401	491

The average overall speed of all passenger and mixed trains in the same period was 14.2 miles an hour. In the case of the fastest train, it was 21.7 miles an hour.

XI. — Conclusion.

The World is now passing through an almost unprecedented economic crisis. On the railways, this is further aggravated by competition from other forms of transport. In civilised countries, especially in Europe and North America, the railway system may be taken as completed. The gauge question no longer arises in these countries, nor in Russia with its extensive broad-gauge system.

There are, however, many countries with few or no railways. Amongst these may be included the Islands of Borneo and New Guinea, as well as many others larger than most European countries (45). These, however, are backward countries, in which railways are not likely to be built for some time.

There are others, however, in which this question is an important one and where the gauge ought to be carefully investigated. The African Continent first of all requires consideration. At the end of 1930, that Continent had only

(45) The area of Borneo is 282 000 sq. miles, and New Guinea 303 000 sq. miles; the former has a population of 2 700 000 inhabitants, the latter only 900 000.

some 41 600 miles of railways, i.e. 0.45 mile per 100 square miles, and 3.7 miles per 10 000 inhabitants. The greater part of these railways were 3′ 6″ [46] or metre-gauge [47], the difference between which is so slight that a common service could be run, if need be, say by the use of interchangeable axles as is done for the standard and Russian gauges.

The 3′ 6″ gauge could be taken as the standard African gauge to which all new African railways should be built. It is satisfactory to note that the Congo-Océan line, 317 miles long, in French Equatorial Africa, opened on the 1st July 1934, is laid to this gauge.

It is regrettable, on the other hand, that the Australian Federal Transcontinental Railway should have been built to 4′ 8 1/2″ gauge in anticipation of this becoming the standard gauge of the Continent. Now, 14 040 miles or 50.8 % of the Australian lines are 3′ 6″ gauge, and this gauge is much more suitable for their light traffic than the standard European gauge of 4′ 8 1/2″, and still more so than the broad gauge of Victoria and South Australia, the mileage of which lines is 6 060. It seems preferable to convert these railways and those of New South Wales, 13 235 miles in all, to the Cape-gauge than to convert the existing Cape-gauge lines to standard-gauge. As we have already seen above, a 3′ 6″ gauge line can be as efficient as a standard-gauge line, provided it is suitably equipped, as for example, the Japanese or South African systems.

Unlike the other countries just mentioned, in South America and especially in Brazil, the metre-gauge has been adopted.

Central Brazil still has no railways. Any railways built there will certainly be metre gauge, seeing that the latter is used not only in Brazil (with 17 870 miles in existence) [48], but also in North Argentina (7 330 miles) and in Bolivia.

As regards Asia, the Turkish Railways were extended considerably immediately after the war. Their total length is now some 3 100 miles. The gauge is the standard, which may be considered as a mistake, as the traffic is very small [49], and may be so for a long time as the country is generally poor and thinly populated. The same remarks apply to Persia where a standard-gauge line 1 020 miles long is now under construction [50].

The largest railway system still to be built is the Chinese. Actually there are only 6 200 miles in China proper (excluding Manchuria, Thibet, and the Western Provinces), or 0.40 mile per 100 square miles and 0.15 miles per 10 000 inhabitants [51]. 93 % of the railways are standard-gauge and the Chinese Government intends in future to build to this gauge alone, although in spite of the great density of the population metre-gauge lines could handle the traffic, as is done on the Japanese railways.

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(46) In all, 23 000 miles or 55 % of the total African mileage. This includes 1 093 miles of 3′ 5 35/64″ gauge which in practice can be likened to the 3′ 6″ gauge.

(47) 7 770 miles or 19 % of the total length.

(48) On the 31st December 1931.

(49) For the year 1931/32, the average traffic on the Turkish Railways (mileage 2 110) was only 80 000 passenger-miles and 111 200 net ton-miles per mile.

(50) See the article by Dr. O. Blum in the *Verkehrstechnische Woche*, 1933, pp. 537, 552 and 567.

(51) The area of China proper is 1 530 000 square miles; it has 460 millions inhabitants, or an average of 300 per square mile.

As many parts of the country are mountainous, a metre or 3′ 6″ gauge line would save much money. There is no doubt, however, that the gauge question will be solved in favour of the standard gauge, with the inevitable consequence of reducing the length that could have been built at the same cost.

We can only hope that in the interests of the people in countries still inadequately provided with railways, the metre or 3′ 6″ gauge will be adopted in preference to the 4′ 8 1/2″, as either of the former gauges can meet all requirements at lower cost.

[625 .234]

Air conditioning of railway vehicles,

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(*Le Génie Civil.*)

Several railways, both French and foreign, put a number of streamlined railcars (1) into service in 1934. Passengers who made long journeys in these units during hot weather suffered from the excessive temperature inside these vehicles.

If streamlining is to be effective there must be no large openings in the body sides such as the drop lights of ordinary stock; moreover, the weight of the vehicle can be reduced if there are no drop light frames. The compartment, therefore, becomes to all intents and purposes closed, and it is easy to understand that in the absence of suitable ventilation the journey in what amounts to a « hothouse » soon becomes intolerable, unhealthy, and even dangerous. The experimental railcar sets had, it is true, been provided with « static » ventilation systems and even with electric fans; however, these systems have been found quite inadequate and practically non-operative.

A more complete investigation became necessary, and specialists in ventilation matters were consulted (2). At the present time, the rakes under construction are being fitted with equipment to new designs, and in addition information is now available as to the practice abroad, particularly in the United States, for solving the problem.

The object of this article is to show that the complicated and delicate problem before us can be solved in a satisfactory way. This can be done by adapting to railcars the principles of air conditioning used in buildings occupied by large numbers of people, such as meeting halls, hospitals, cinemas, etc., of course with due regard to the special needs of high-speed rolling stock which must be light and have little air resistance.

The following points will be dealt with in turn :

1. In what should air conditioning of railcars consist?
2. How should it be done?
3. Methods used in the United States.
4. Suggested method for use in France.

Air conditioning of railcars. — Air conditioning of railcars consists in making the passengers comfortable by artificial climatic conditions under which they will feel at ease throughout the journey, whatever the outside atmospheric conditions.

This well-being will be shown by the physical condition of the passenger, who should not feel tired because of the atmosphere in which he lives during the journey.

The artificial atmosphere is defined by the following characteristics :

Winter : a) A temperature of 18 to 20° C. (64 to 68° F.);

b) Sufficient ventilation by air free from dust and noxious gases, at the rate of about 25 m³ (900 cu. feet) of pure air per passenger per hour;

c) A constant humidity of 50 to 60 %;

---

(1) Some of these railcars were described in the *Génie Civil*, particularly in the 7th April, 19th May, 2nd June, 7th July, 15th September, and 27th October 1934 numbers.

(2) As long ago as in 1929, the Paris-Orléans Railway used a successful air cooling and ventilation system during hot weather. A description was given in the *Génie Civil* of the 4th January 1930, page 9.

d) Freedom from draughts and absence of dust in motion.

Summer : *a*) A maximum temperature of 26° C. (79° F.) even on the hottest days;

b), *c*) and *d*) As in Winter.

Between seasons, as in Winter.

Pratical application of air conditioning. — When designing air conditioning equipment, the climatic and economic conditions (weight, volume, power absorbed, first cost, etc.) have to be taken into account.

The general principles of air conditioning may be laid down as follow :

A certain calculated quantity of air is prepared in a « conditioning chamber » by adjusting the temperature, humidity, and cleanliness of the air as necessary. The incoming air thus possessing well defined physical properties is passed into the enclosed space (room, compartment) to be dealt with, the climatic conditions being modified by giving or taking away heat and water vapour corresponding to the quantities given up in the room, either by the people in it, or by a source of heat and of cold in the room itself or outside it. The final condition of the air in the room therefore depends on the quality and quantity of the air introduced.

In Summer the air introduced can be:

1. Drawn in from outside and used without treatment;

2. Cooled in the conditioning chamber by simple evaporation of water;

3. Cooled down in the conditioning chamber by cold water when the supply is sufficient;

4. Cooled down in the conditioning chamber by cold water cooled in a refrigerator.

5. Cooled down in the conditioning chamber by means of water cooled down itself by means of ice.

When the installation is a fixed one, the three last methods are available; the method selected will be decided by the expected financial results.

When the equipment has to be built in rolling stock, the third solution cannot be considered. The choice between the remaining methods will depend on the climatic and economic conditions, (weight, dimensions, etc.).

Methods used in the United States of America.

The climate in the United States is one of violent extremes. For this reason the equipments are very large as will be seen from the following examples from the *Transactions of the American Society of Mechanical Engineers*, of September 1934.

The Burlington Zephyr. — This train which can run at 160 km. (100 miles) per hour, consists of three vehicles, one a 600-H.P. diesel-electric motor coach. It is intended to make runs of 600 to 1 200 miles and can carry 60 to 70 passengers. The train consists of an engine room, luggage compartment, three passenger sections with buffets, saloon, etc.

A double heating system is fitted; heating in conjunction with the air conditioning plant, and heating by direct radiation. When the temperature is not too low, the three passenger compartments are heated by radiators in the conditioning equipment. The warm air is distributed through the air conditioning inlets near the ceilings. In very cold weather, the additional heat is given by radiators on each side of the body near the floor, following the usual practice.

The temperature is controlled automatically by thermostats. All heating pipes are copper, as are the radiators, and this has saved much weight. With this system of heating a temperature of 20° C. (68° F.) can be maintained in the passenger compartments with an outside temperature of — 35° C. (— 31° F.). The steam required is produced by an oil-fired boiler, the pressure and water level being regulated automatically. The

condensed water from the heating system is returned to the feed tanks. The 250-l. (75 Br. gall.) fuel tank is large enough for a 800-km. (500 miles) run in the worst weather conditions.

Each passenger compartment has its own conditioning and distribution plant. The refrigerating machines use freon [1] and are carried under the floor with the accessories.

The fresh air drawn in from outside as well as the air withdrawn from the compartments is filtered before being distributed. The temperature is automatically controlled by thermostats. The side lights, which can be opened, are kept closed when the air conditioning plant is running.

The Union Pacific high-speed lightweight streamlined trains. — This Company has built a three-car train which, like the Zephyr, is a high-speed lightweight set. It includes a 600-H.P. diesel-electric motor car and can run at 140 to 170 km. (90 to 110 miles) an hour. The whole train is air conditioned by a single central plant, the treated air being distributed and collected by three ducts, one along the centre line of the roof, and the others on each side below the floor line. These ducts extend the full length of the two passenger vehicles, and are connected together between the vehicles by flexible pipes. The air conditioning plant is fitted in the luggage compartment.

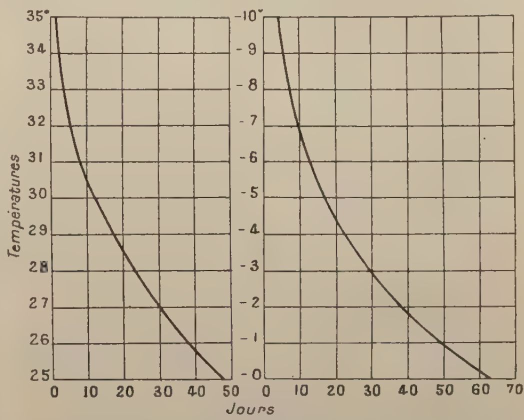
In Summer the cooled air is distributed by the top duct and withdrawn by the two lower ones. In Winter the heated air is distributed through the lower ducts and withdrawn through the upper one.

An oil-fired boiler is provided for heating and a freon refrigerator for cooling. The heat insulation is extremely thorough, Rockfloss, an incombustible material of high heat and sound insulating properties being used.

(1) Freon is dichloro-difluoromethane CCl_2F_2 (non-toxic gas).

Equipment proposed for use in France.

A detailed examination of Summer temperatures in France shows that the number of days with temperature in the shade exceeding 28° C. (82.4° F.) is on the average 20 (observations in the Paris region between 1890 and 1924). The number of days with a temperature below — 5° C. (23° F.) average 17 a year (figs. 1 and 2).



Figs. 1 and 2. — Number of days during which the maximum and minimum temperatures exceed the temperatures represented by the ordinates.

The humidity figures taken from the *Bulletin d'Etudes de l'Office National Météorologique* for given temperatures average 65 % to 32 %, when the temperature varies from 20° to 37° C. (68° to 98° F.) in the Paris region during the months of July and August in the years 1932, 1933, and 1934, as shown in figure 3.

Now let us consider the different ways of bringing about the conditions required to make passengers comfortable, namely a temperature of 20° C. (68° F.)

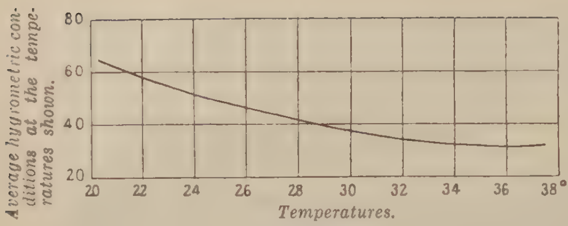


Fig. 3. — Average hygrometric conditions of the air at different temperatures.

and a humidity of 50 % in Winter, and 26° C. (79° F.) and 60 % humidity in Summer.

Heating. — In principle, an enclosure densely occupied for short periods (the case of railcars) ought to be heated by conditioned air, as this is the method by which the compartments can be brought quickly to the desired temperature. Uniform temperature is obtained by circulating a large volume of air, and then withdrawing a large part of it, which is then treated and mixed with new air. It is better to introduce the air at the roof as this does not disturb any dust brought in by the passengers. The collecting ducts on the other hand should be arranged near the floor to make the distribution of the air as uniform as possible (fig. 4).

On diesel railcars, the heat units lost to the cooling water ought to be recovered for heating purposes (fig. 5).

This would make the heating very economical, as it would not be necessary to provide from outside sources the heat units specially required for heating purposes. In this case the best arrangement is to recover the heat hitherto wasted in the cooling water and not that in the exhaust gases. Air heating by the exhaust gases is unsatisfactory as, owing to the high temperature of the heat exchanging surfaces, the little dust left in the air in spite of the filters is carbonized and the exhaust gases may leak through the exchange surfaces, if the joints are not quite tight. Furthermore, such plant is difficult to regulate, and it is bulky and heavy. Besides this, there is sufficient heat in the cooling water for the purpose.

As the amount of heat units required varies considerably with the season, automatic regulation by a thermostat is provided in the carriage and controls a valve which regulates the quantity of water passing through the heating radiators. The surplus cooling water will not pass through the heating radiators but straight to the coach radiator which will be fitted with thermostatic shutters as in automobile practice. As a precaution in case there is insufficient heat to heat the air owing to running the engine light some considerable time, an electric thermostat is fitted in the hot air leaving the ventilator and stops the latter

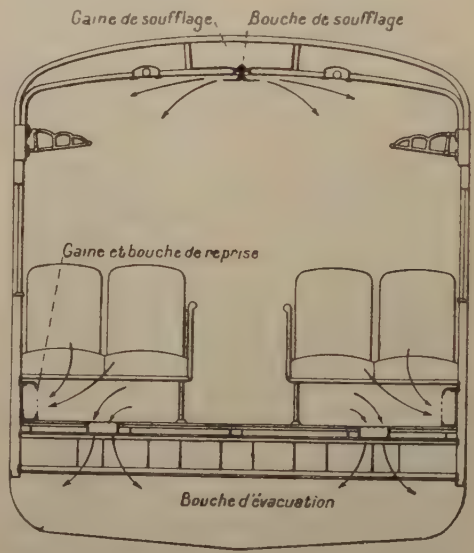


Fig. 4. — Arrangement of the ducts and orifices through which air distributed, drawn up for recirculation or exhausted.

Explanation of French terms :

Gaine de soufflage = Delivery duct. — Bouche de soufflage = Air inlet. — Gaine et bouche de reprise = Orifice and duct for air to be recirculated. — Bouche d'évacuation = Exhaust.

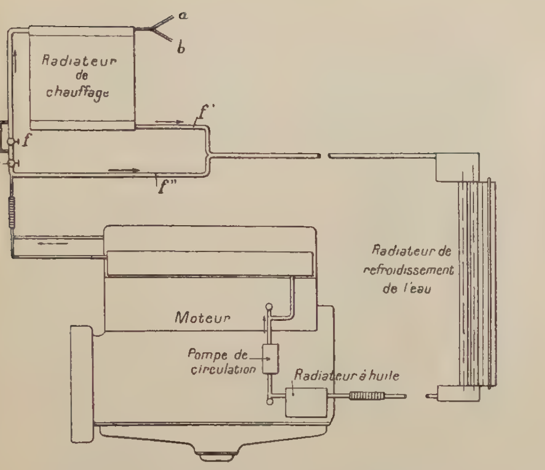


Fig. 5. — Diagram of heating plant using heat recovered from the cooling water of the diesel engine.

Note :

Radiateur de chauffage = heating radiator. — Moteur = engine. — Radiateur de refroidissement de l'eau = water cooling radiator. — Pompe de circulation = circulating pump. — Radiateur à huile = oil-cooling radiator. — *a* = air pipe. — *b* = filling pipe. — *c* = regulating valve. — *d* = bypass, 100 to 200 l./h. (3.5 to 7 cu. ft. per hour). — *e* = stop valves. — *f* = automatic valve. — *f'* discharge of 3 600 l./h. = 127 cu. ft. per hour (automatic valve open) or 100 to 200 l./h. = 3.5 to 7 cu. ft. per hour (automatic valve shut). — *f"* discharge of 3 600 l./h. = 127 cu. ft. per hour (automatic valve open), or 7 200 l./h. = 254 cu. ft. per hour (automatic valve shut).

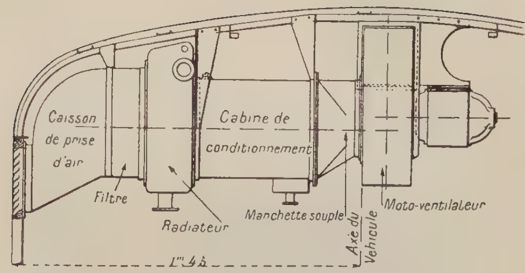


Fig. 6. — Air conditioning set, Neu system, for a railcar.

Note :

Caisson de prise d'air = air inlet chamber. — Filtre = filter. — Radiateur = radiator. — Cabine de conditionnement = air conditioning chamber. — Manchette souple = flexible sleeve. — Axe du véhicule = centre line of vehicle. — Moto-ventilateur = motor driven ventilator.

when the temperature of the air blown in falls below 20° C. (68° F.).

Very light honeycomb radiators will be used when the pressure they have to stand is low. Finned tube radiators to stand a pressure of 10 kgr. (142 lb. per sq. inch) will be used, however, when water or steam under pressure is used.

The advantage of this system is that, besides heating the air, it provides effective and controlled ventilation with filtered and slightly humid air. The plant is simple and light (figs. 6 and 7). Generally the radiators of the air conditioning sets are heated by steam or hot water, as in ordinary radiator practice.

Cooling and refrigeration in Summer. — As we have seen, a comfortable temperature involves freshening the ventilating air during certain periods and in others cooling it down considerably. The following table brings out the different characteristics of the proposed plants for a 60-seater coach. In this

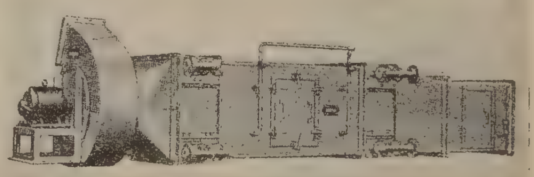


Fig. 7. — View of an air conditioning set, Neu system, for a railcar.

table *t* is the temperature and Θ the humidity of the air. The graph (fig. 8) brings out the efficiency of the different methods used.

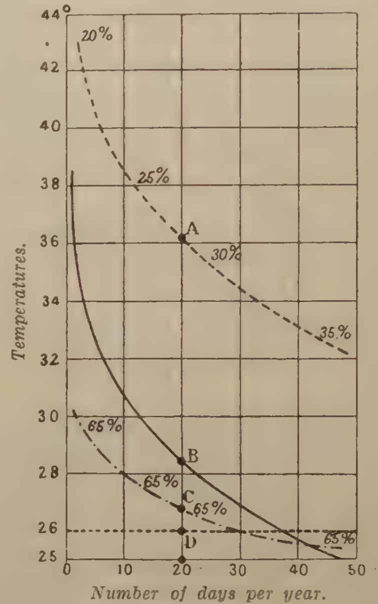
The heat from outside sources is taken as 5 000 kgr./cal. (19 840 B.T.U.). The heat due to the passengers is 100 × 60 = 6 000 kgr./cal. (23 800 B.T.U.). The quantity of water evaporated by the passengers is 60 × 55 grammes = 3 300

Characteristics of the equipment and working conditions of an air-conditioning plant for railway use.

Method.	Outside conditions. Temp. t,°	Outside conditions. Hum. Θ,°/o	Condition of air blown in. Temp. t,°	Condition of air blown in. Hum. Θ,°/o	Conditions obtained. Temp. t,°	Conditions obtained. Hum. Θ,°/o	Total power consumed. H. P.	Quantity of water used per hour.	Quantity of ice used per hour.	Weight of sets: in aluminium including radiators (empty).	Weight of sets: pumps, tanks and refrigerators (empty).
Outside air	30 C. 86 F.	38	30 C. 86 F.	38	38 C. *100.4 F.*	25	1	...	...	300 kgr. *662 lb.*	...
Outside air, refreshed	30 C. 86 F.	38	20 C. 68 F.	100	27 C. *80.6 F.*	65	1.2	17 l. *0.6 cu. ft.*	...	410 kgr. *904 lb.*	150 kgr. *331 lb.*
Outside air, water-cooled	30 C. 86 F.	38	17 C. 62.6 F.	100	26 C. *78.8 F.*	60	2	4 000 l. at 12° C *140 cu. ft. at 53.6° F.*	...	410 kgr. *904 lb.*	...
Outside air, cooled by refrigerating machine	30 C. 86 F.	38	17 C. 62.6 F.	100	26 C. *78.8 F.*	60	10	...	...	400 kgr. *882 lb.*	2 800 kgr. *6 173 lb.*
Outside air, ice-cooled.	30 C. 86 F.	38	17 C. 62.6 F.	100	26 C. *78.8 F.*	60	2	...	230 kgr. *507 lb.*	400 kgr. *882 lb.*	300 kgr. *662 lb.*

grammes (6.5 lb.). The quantity of air circulated is 4 000 m³ (141 200 cu. feet) or 4 700 kgr. (10 360 lb.) per hour.

The table and figure 8 show that in France a refrigerator would be used



------ Method by ventilation.

—.—.—.—.—. Method by evaporation.

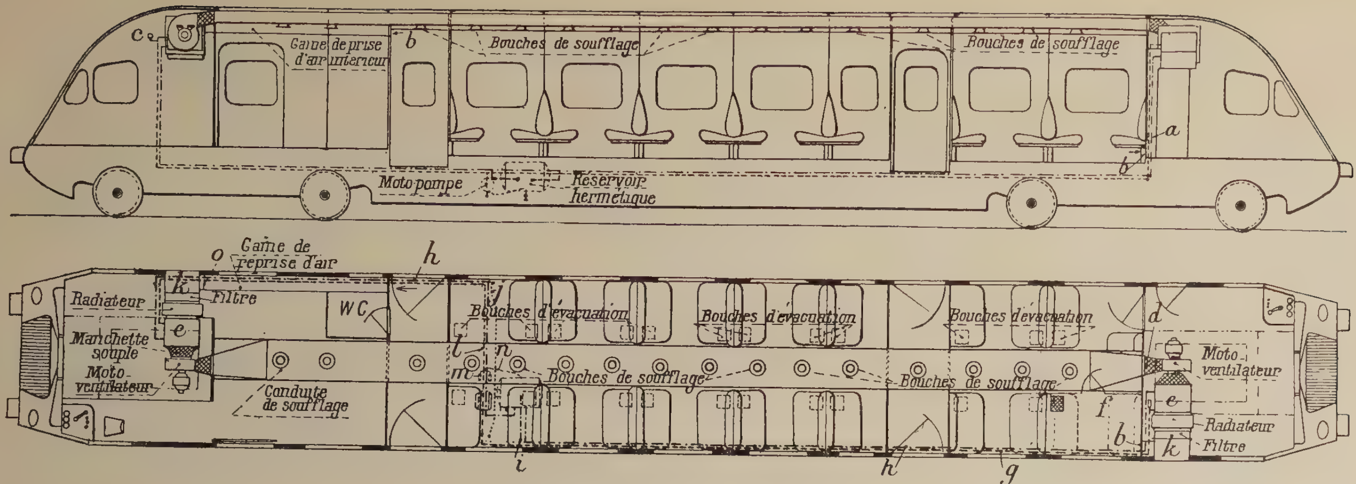
. . . . Method by refrigeration.

Example: 20 days per annum, the maximum outside temperature exceeds 28.5° C. (83.3° F.); with the ventilation method A, a temperature of 36° C. (96.8° F.) is obtained, by evaporation, C, 26.8° C. (80.3° F.), and by refrigeration D, 26° C. (78.8° F.).

Fig. 8. — Points plotted for results obtained by different methods, the exterior conditions being defined by the full-line curve, identical with that of figure 1 and the corresponding hygrometric state, taken from figure 3.

too short a time each year to justify its cost.

The use of ice, on the other hand, would be more economical in periods of great heat, as the great weight of the refrigerator and the accessory plant to provide the power needed would be saved; moreover such equipment is not needed during the greater part of the



Figs. 9 and 10. — Vertical and horizontal sections of a Lorraine Dietrich rail motor coach fitted with air conditioning plant.

a = duct for inside air. — b = inlet through which inside air is drawn up. — c = pressure gauge. — d = flexible sleeve. — e = conditioning chamber. — f = mail compartment. — g = water supply. — h = return water. — i = level gauge cock. — j = tank filling pipe. — k = air inlet chamber. — l = water supply. — m = motor-driven pump. — n = suction pipe. — o = shutter. — Gaine de prise d'air intérieur = duct for returning inside air. — Bouches de soufflage = diffusers of conditioned air. — Moto-pompe = motor-driven pump. — Réservoir hermétique = air-tight reservoir. — Manchette souple = flexible sleeve. — Bouches d'évacuation = air outlets.

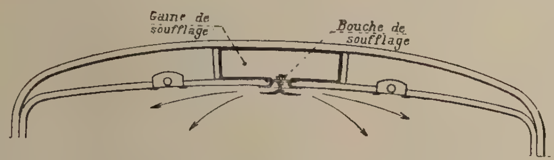


Fig. 11. — Arrangement of air diffuser.

Fig. 12. — View of a radial diffuser.

year. But the period during which the air could be cooled merely by the evaporation of water is much longer. As is known, this process consists in finely spraying the water into the air, the heat to convert this water into vapour being taken from the air, the temperature of which falls some 2° C. per gramme of water evaporated per cubic metre of air.

The above table shows that the air could be cooled from an outside temperature of 30° C. (86° F.) with 38 % of humidity to 20° C. (68° F.) with 100 % of humidity.

Figure 7 shows an air conditioning chamber equipped for cooling the air by this method. It contains : filtering cells with oiled deflector plates for removing dust from the air; a number of sprays with cleaning baffles; and lastly a motor-driven centrifugal fan. The spray nozzles are fed by a motor-driven pump which draws the water from a tank located below the level of the chamber so that any excess water can drain back into it and be used again. The water circulation thus takes place in a closed circuit. Figures 9 and 10 show the application of the equipment to a railcar.

The ice tank is filled with ice, when required for cooling the air; the water is pumped over the ice and is cooled thereby. The circulation ducts ought to be insulated effectively.

Introduction of air. — As the heating or cooling is by distributing conditioned air, a large volume has to be set in motion in a limited space.

Fans are used to introduce the air, as in this way the air can be circulated whether the vehicle is running or stationary, the whole installation can be regulated properly, and finally the air can be distributed uniformly by the different diffusers throughout the vehicle. By using centrifugal types of fans, the size of the ducts can be reduced and air can be drawn in from outside in spite of the vacuum produced by the rake running at high speed.

The best results are obtained, as regards heating and cooling, when the air is renewed 30 to 40 times an hour. Special diffusers have to be used to prevent draughts, owing to the small size of the compartments; the ducts are flat and arranged in the roof. The diffusers offer little obstruction. The design shown in figures 11 and 12 offer a resistance one third that of an orifice in thin plate; they also diffuse the air very well, the air leaving the nozzle in fine threads moving radially.

The air distribution, which takes place uniformly throughout the coach and along the top is regulated once and for all, the passengers having no control over it. The head guard can alter the quantity of air delivered by means of the louvres fitted on the suction side of the fans.

It is on these lines that we have designed the air-conditioning plant for a 300-H.-P. railcar, built by Messrs. *Société Lorraine des Anciens Etablissements de Dietrich et C^ie^*, for the French State Railways. The gear is simple and weighs no more than the gear usually fitted for heating railway carriages without ventilating or cooling them. The power for the fans and pump fitted in this 60-seater vehicle varies from 1 to 2 H.-P. according to outside weather conditions.

In Summer the air is filtered, then washed and cooled by evaporation; a pleasant temperature is maintained inside the vehicle. In Winter the vehicle is properly ventilated by filtered air, the heat uniform, and the temperature controlled by thermostats. The passengers will therefore travel in the most comfortable conditions.

This arrangement, moreover, meets the specified economic requirements : low power consumption, light weight, compactness, and low cost.

[621. 132.5 (.47)]

Non-articulated 4-14-4 type locomotive built in Russia (*),

by D. BABENKO.

(Railway Mechanical Engineer.)

A study to determine the heaviest type of freight locomotive that could be used on Russian railroads was initiated in 1930. The investigation was coupled with considerations involving the adoption of automatic couplers. Operating conditions imposed the following restrictions under which the design was to be worked out :

1. Locomotive must operate on existing light track where the rails weigh only 76 lb. per yard. To relay the track with rails weighing 100 lb. or more per yard and to replace the present light bridges was considered prohibitive.

2. Curves in main-line track of 525-foot radius must be negotiated at full speed, and even sharper curves at reduced speeds.

3. Operating speeds up to 43.5 m. p. h.

4. Trains of 2 750 short (2 450 Engl.) tons to be run at a speed of 15 m. p. h. on specified heavy grades.

5. Wear or track on curves and side thrusts to be as low as possible.

6. Stresses on the track, due to dynamic augment at highest running speeds, not to be dangerous despite the light weight of the rails.

7. Fuel to be coal of available low grade and slow-burning quality.

8. Axle load limited to 20 metric tons, or 44 000 lb.

9. Tractive force at least 60 000 lb. at speed.

It will be readily seen that the above restrictions made the working out of the design a particulary difficult one and raised many problems which had to be solved before construction could be started. Calculations showed that a locomotive which would meet the requirements would have to weigh about 308 000 lb. on the drivers and have a rated starting tractive force of 88 000 lb. Furthermore, the adhesive weight would have to be distributed on seven axles.

The use of articulated locomotives, such as the *Mallet* or the *Garratt* was naturally given consideration, but in view of their rather low efficiency and heavy maintenance costs, the adoption of an articulated design was not considered advisable.

The only alternative to an articulated design was the use of a larger number of coupled axles in a locomotive having a single frame—a greater number than on any locomotive then in operation in Russia. Continuing the investigation, which was started in the spring of 1930, it was found that non-articulated locomotives of the 2-10-0 type were being operated successfully in Germany, also locomotives of the 2-10-2, 2-10-4, 4-10-2 and 4-12-2 types in the United States. These locomotives were of the desired power, but in most cases they had an axle load in excess of 60 000 lb. Due to the greatly restricted axle loads—44 000 lb. per axle—necessary for operation on 76-lb. rails, a locomotive of the desired power would re-

(*) From a translation of an article which appeared in « The Motive Power », published in Moscow, U.S.S.R.

quire the employment of seven coupled axles, or a locomotive of the 2-14-2 type. A preliminary design of a two-cylinder, 2-14-4 type locomotive was worked out in the early part of 1931, for which a four-wheel trailing truck was provided, due to the large firebox found necessary.

After the preliminary design had been gone over and had received tentative approval, it was decided that it would be advisable before starting contruction to send representatives to other countries to investigate the results obtained from locomotives having five or six coupled axles. Accordingly, three engineers were sent to Germany and later to the United States, where they investigated manufacturing and maintenance facilities and inspected and rode on a number of heavy, non-articulated locomotives.

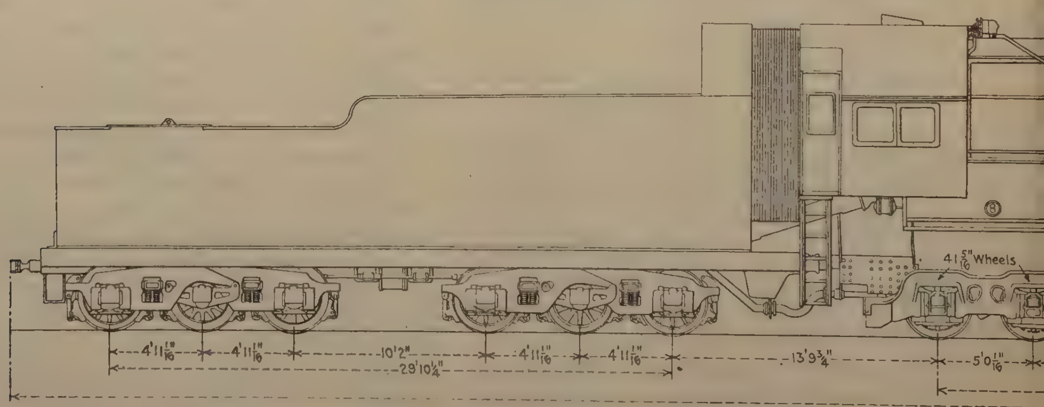
Upon their return the preliminary designs for a 2-14-4 type locomotive were again gone over in light of the information gathered and a modified design was worked out for a locomotive of the 4-14-4 type. After the design had been checked and approved an order for the construction of a sample locomotive was given to the Lugansk Locomotive Works.

The locomotive has now been completed and has made some trial runs before being placed in service. Handling a train of 1 400 short tons, a speed of 25 m. p. h. was obtained on a heavy grade, under which conditions the locomotive developed 3 000 H.-P. When cold the locomotive was pulled around a curve of 453-ft. radius; under steam it passed over a curve of 820-ft. radius at a speed of 28 m. p. h.

This locomotive weighs 458 435 lb. in working condition, of which 308 560 lb. is carried on the 14 driving wheels. The four-wheel engine truck carries a load of 68 325 lb. and the four-wheel trailing truck, 81 350 lb. The driving wheels are 63 in. in diameter, the two cylinders are 29 1/8 in. in diameter, and have a stroke of 31 7/8 in., while the boiler pressure carried is 242 lb. per sq. in. The rated tractive force on an 85 % basis is consequently 88 250 lb. The light weight of the locomotive is 399 600 lb.

The wheel base of the locomotive is 56 ft. 9 7/8 in., and that of the locomotive and tender, 105 ft. 5 7/8 in. The driving-wheel base is 32 ft. 11 5/8 in. The length of the locomotive between coupler faces is 67 ft. 11 5/8 in., and the combined length of the locomotive and tender is 110 ft. 8 3/16 in.

The tender weighs 275 500 lb. in working order, or 130 040 lb. light, and is mounted on two six-wheel trucks of the



Side elevation showing engine and ten

Buckeye type, of 9 ft. 10 1/8 in. wheelbase. It has a capacity for 11 620 U. S. gallons of water and 24.2 tons of coal. The length of the tender between coupler faces is 44 ft. 1 1/4 in. and the wheel base 31 ft. 6 1/8 in.

Many of the features of this unusual locomotive are particulary interesting.

Especially noticeable is the large size of the boiler and the firebox. The boiler is of the straight-top radial-stayed type, the center line being 11 ft. 11 3/4 in. above the top of the rail. The total length of the boiler is 58 ft. 7 5/8 in. and its weight is appoximately 132 000 lb.

The firebox is 15 ft. 9 in. long and 8 ft. 2 7/16 in. wide, which gives a grate area of 129.2 sq. ft. Such a large grate area would not be required were the coal not of such a low grade. The grates are of the shaking type and a grate shaker operated by either steam or compressed air is provided. The coal is fed by a mechanical stoker. The ash pan is of the hopper type.

A combustion chamber, 8 ft. 2 7/16 in. long, is provided which increases the firebox volume to 865.2 cu. ft. A brick arch is applied, the arch being carried on four arch tubes of 3 1/2 in. diameter.

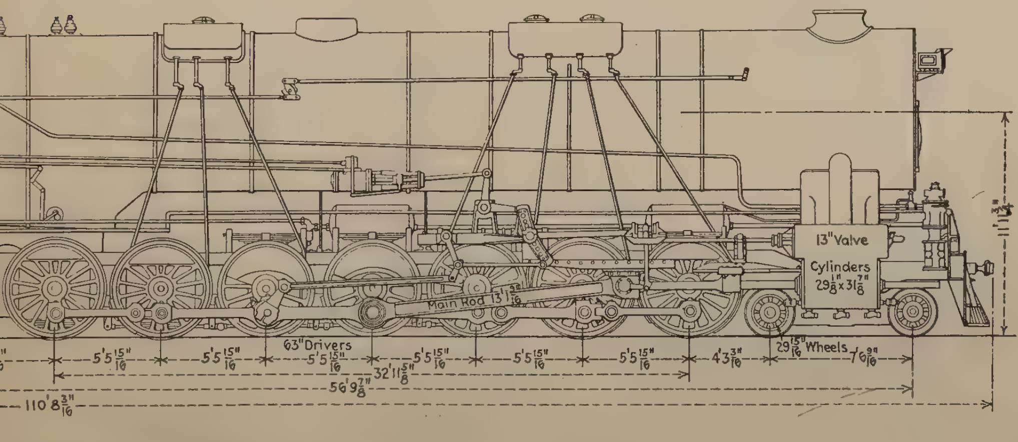
There are 138 fire tubes, 2 3/4 in. outside diameter, and 48 flues, 6 3/4 in. in diameter. Tubes and flues are 22 ft. 11 9/16 in. long. This great length accounts for the use of tubes and flues of such large diameter.

The Chussov superheater is of the six-tube type, the outside diameter of the tubes being 1 3/16 in. The elements extend back to within 22 13/16 in. of the rear tube sheet.

The evaporative heating surface of the boiler has an area of 4 822.7 sq. ft., of which 594.4 sq. ft. is in the firebox and 4 227.3 sq. ft. in the tubes and flues. Adding 1 872.9 sq. ft. superheating surface brings the combined evaporating and superheating surface to 6 695.6 sq. ft.

The evaporative capacity of the boiler is estimated to be 73 716 lb. per hour, which corresponds to a potential or boiler horsepower of 3 880. Assuming a combustion rate of 82 lb. per sq. ft. of grate per hour, the total amount of coal burned would be 10 594 lb. per hour. If one horsepower could be developped for each 2.65 lb. of coal, the total horsepower would be 4 000.

A particularly interesting feature of the boiler construction is the extensive manner in which welding was employed, mainly to keep down the weight,



e Russian 4-14-4 type locomotive.

Table of dimensions, weights and proportions of the Russian 4-14-4 type locomotive.

Railroad	U. S. S. R. (Russian).
Date built	1934.
Builder	Lugansk Loco. Works.
Type of locomotive	4-14-4.
Service	Freight.
Track gage	5 ft.
Cylinders, diameter and stroke (2)	29 1/8 in. by 31 7/8 in.
Valve gear, type	Walschaerts.
Valves (piston type) :	
Size	13 in.
Maximum travel	7 13/16 in.
Steam lap	2 in.
Exhaust clearance	0 in.
Lead in full gear	5/16 in.
Weights in working order :	
On drivers	308 560 lb.
On front truck	68 325 lb.
On trailing truck	81 550 lb.
Total engine	458 435 lb.
Tender	275 500 lb.
Wheel bases :	
Driving	32 ft. 11 5/8 in.
Total engine	56 ft. 9 7/8 in.
Total engine and tender	100 ft. 5 7/8 in.
Wheels, diameter outside tires :	
Driving	63 in.
Front truck	29 15/16 in.
Trailing truck	41 5/16 in.
Journals, diameter and length :	
Driving, main (No. 4)	12 5/8 in. by 14 15/16 in.
Driving, tandem (No. 5)	11 in. by 14 15/16 in.
Driving, others	9 7/16 in. by 14 15/16 in.
Front truck	7 1/2 in. by 13 3/4 in.
Trailing truck	7 7/8 in. by 13 1/4 in.
Boiler :	
Type	Radial stayed.
Steam pressure	242 lb.
Fuel	Low grade coal.
Firebox, length and width (grate)	189 in. by 98 7/16 in.
Arch tubes—number and diameter	4—3 1/2 in.
Combustion chamber-length	98 7/16 in.
Tubes—number and diameter	138—2 3/4 in.
Flues—number and diameter	48—6 3/4 in.
Length over tube sheets	22 ft. 11 9/16 in.
Firebox volume	865.2 cu. ft.
Grate type	Shaking.
Grate area	129.2 sq. ft.

Heading surfaces :

Firebox and combustion chamber	543.2 sq. ft.
Arch tubes	52.2 sq. ft.
Firebox, total	595.4 sq. ft.
Tubes	1 942.1 sq. ft.
Flues	2 285.2 sq. ft.
Total evaporative	4 822.7 sq. ft.
Superheating	1 872.9 sq. ft.
Combined evaporative and superheating	6 695.6 sq. ft.

Special equipment :

Brick arch	Yes.
Superheater	Chussov.
Exhaust steam injectors	2.
Stoker	Yes.
Booster	No.

Tender :

Water capacity	11 620 gal.
Fuel capacity	24.2 tons.
Trucks	6-wheel.

General data (estimated) :

Rated tractive force, 85 %	88 250 lb.
Boiler horsepower	3 880 H.P.
Speed at 1 000 ft. piston speed	35.3 m.p.h.
Piston speed (ft. per min.) at 10 m.p.h.	283.5.

Weight proportions :

Weight on drivers ÷ total weight engine, %	67.4
Weight on drivers ÷ tractive force	3.5
Total weight engine ÷ potential horse-power	118.2
Total weight engine ÷ combined heating surface	68.5

Boiler capacity and proportions :

Evaporative capacity, lb. per hr. (with heater), estimated	73 716
Equivalent evaporative (sq. ft. heating surface per hr.) (with heater), estimated	15.3
Firebox heat. surface, % com. heat. surface	8.9
Tube-flue heating surface, % combined heating surface	63.1
Superheating surface, % comb. heat surface	28.0
Firebox heating surface ÷ grate area	4.6
Tube-flue heating surface ÷ grate area	32.7
Superheating surface ÷ grate area	14.5
Combined heating surface ÷ grate area	51.8
Potential horsepower ÷ grate area	30.0
Combined heating surface ÷ potential horsepower	1 725
Tractive force ÷ combined heating surface	12.28
Tractive force × diameter drivers ÷ combined heating surface	774

but partly to permit of the use of sheets of readily available sizes. All welded seams are of V shape and are located between lines of staybolts. The firebox sheets, both inside and outside, are welded, being formed of several sheets joined together by welding. The crown sheet and back boiler head are also made of two or more sheets with welded joints.

The boiler is fed by two exhaust-steam injectors having a capacity of 95 to 100 U. S. gallons per minute. Two Friedman live-steam injectors, having a capacity of 45 to 48 U. S. gallons per minute are also provided. Two blow-off cocks are applied on each side of the firebox.

The frames are cast steel, being the first ones made at the Lugansk Locomotive Works. The thickness or width of the frames is 5 1/2 in.

One of the most difficult of the problems which the design of this locomotive presented was the provision for safely passing around sharp curves at considerable speed and the avoidance of heavy side thrusts and side wear of the rails due to the long wheel base. As will be noted from the illustration of the locomotive, the cylinders are coupled to the fourth pair of drivers.

The third, fourth and fifth pairs of drivers have bald tires 6 7/8 in. wide. The first and second pairs of drivers are arranged to have a lateral motion of 1 1/16 in. each side of the center. No lateral motion is provided for on the sixth pair of drivers, but the seventh pair has provision for 1 3/8 in. lateral motion each side of the center. The first truck is designed for 5 11/16 in. lateral motion to the right and left and the trailing truck with 1 3/8 in. lateral motion. The lateral motion of the driving wheels is provided for by clearance between the driving boxes and the hub liners. A lateral-motion device with equalizer spring suspension is provided on the rear axle.

The driving boxes are cast steel with bronze crown brasses and the usual cellars. Lubrification is by packing from the bottom and wick lubrication from a top reservoir.

Spring rigging follows the usual American pratice—semi-elliptic springs and equalizers located between the upper and lower bars of the frame. The springs are placed on top of the driving boxes, except on the sixth and seventh axles where it was necessary to use underhung springs due to the presence of the firebox. Three-point suspension is provided by dividing the spring rigging into three groups. The first group includes the springs and equalizers—on both sides of the locomotive—of the front truck and the first, second, third and fourth axles. The other two groups are made up of the springs and equalizers on the right- and left-hand sides of the locomotive for the fifth, sixth and seventh axles and for the trailing truck.

Unusual main and side rods.

The design of the rods and motion work presented another interesting problem. As previously stated, the main rods are connected to the crank pins on the fourth pair of drivers. The main rods are 13 ft. 1 9/16 in. long. Despite their great length the distance between the center of the cylinders and the fourth axle is so great that the piston rods are 13 ft. 1 9/16 in. long. To keep down the reciprocating weights and to make unnecessary the employment of piston rods of abnormal diameter, resort was had to a secondary supporting crosshead located midway between the cylinder and the main crosshead. The main crosshead is of the multiple ledge type developed on the Pennsylvania Railroad.

A tandem main rod serves to connect the fourth to the fifth pair of drivers. The eccentric crank for the Walschaerts valve motion is placed on the fifth crank pin. The distance from the

eccentric crank to the reverse link was so great that the eccentric rod was divided and an intermediate supporting rocker arm was introduced. Extension rods are used to support the main cylinder pistons and also the piston valves.

In the side rods connecting the first and second pairs of wheels and also the sixth and seventh pairs universal joints with vertical and horizontal pins are provided to permit the allowed lateral motion. The side-rod crankpin bearings on the first, second, sixth and seventh pairs of wheels are of the ball type. All rods are fitted with floating bushings and are arranged for grease lubrication. Axles and crank pins are hollow bored.

Other details are interesting.

Piston valves are 13 in. in diameter and have a maximum travel of 7 13/16 in. A power reverse gear is fitted.

There are two large sand boxes with 14 pneumatic sanders for supplying sand to the front side of all driving wheels.

A multiple throttle valve with six valves and one pilot valve is installed. There is a stop valve in the dome.

Air brakes are provided, air being supplied by two cross-compound air compressors located on the front deck ahead of the cylinders. Drive brakes are of the Kasantzeff design with brake shoes on the front side of all driving wheels, except those on the front and rear axles where brake shoes are omitted on account of the great amount of lateral motion. Clasp brakes are used on the six-wheel tender.

Notwithstanding the heavy weight of the moving parts (main rod 1 610 lb.; piston, piston rod and crosshead 2 485 lb.) and the high running speed of 43.5 m.p.h. anticipated for the locomotive, it was possible to counterbalance all the rotating masses and the necessary part of the reciprocating parts.

The weights and leading dimensions are given in an accompanying table.

[536 (.06]

The Third International Steam Tables Conference (1).

(From *The Engineer.*)

The following Report of the Third International Steam Tables Conference has been issued.

The Third International Steam Tables Conference was held in the United States of America during the week commencing September 17th, 1934, at the invitation of the Special Research Committee on the Thermal Properties of Steam of the American Society of Mechanical Engineers. Its purpose was to improve and to extend international agreement on the properties of steam in continuation of the work of the London Conference of 1929 and the Berlin Conference of 1930.

The first session of the Conference was opened at the National Bureau of Standards in Washington, D.C., by Dr. Lyman J. Briggs, Director of the Bureau. Greetings from the engineering societies of the United States were extended by Mr. Fred M. Feiker, Secretary of the American Engineering Council. The proceedings of the Conference then continued under the chairmanship of Dr. Alex. Dow, Chairman of the A.S.M.E. Special Research Committee on the Thermal Properties of Steam.

After the necessary formal business had been completed, a committee was formed, in accordance with the procedure followed at previous conferences, to revise and enlarge the International Skeleton Tables. This committee consisted of the entire British and German delegations and Messrs. Osborne, Keyes and Keenan, with Messrs. Heck and Ellenwood as alternates for the American members.

After adjournment of the first meeting of the Conference, Dr. Osborne explained and exhibited the apparatus employed at the National Bureau of Standards for measurement of properties of saturated liquid water and saturated water vapour. The methods and technique of measurement were demonstrated later when Dr. Osborne and his associates executed a typical experiment.

The second session of the Conference was held on Tuesday, September 18th, at the Massachusetts Institute of Technology in Cambridge, Mass., where the delegates were greeted by Dr. Karl T. Compton, President of the Institute. At this session Dr. James A. Beattie, Associate Professor of Physico-Chemical Research, gave an address on the preliminary results of his experimental investigation of the relation between the international scale of temperature and the thermodynamic scale from the ice point to the sulphur boiling point. Afterwards Dr. Keyes and Dr. Smith exhibited the apparatus and explained the methods of measurement which they used to determine the specific volume of superheated steam and compressed liquid water. Dr. Keyes showed also the apparatus he is using for measuring the Joule-Thomson coefficient and the constant temperature coefficient.

At the third session of the Conference, which was held on Wednesday, September 19th, at the headquarters of the American Society of Mechanical Engineers in New York, N. Y., Dr. Calvin W.

(1) See short account of the Second Conference, Berlin, 1930, in the November 1931 issue of this *Bulletin*, p. 999.

Rice [2], Secretary of the Society, welcomed the delegates. The Conference then adjourned subject to call by the Chairman for the final session later in the week.

The committee met immediately thereafter and elected Mr. I. V. Robinson, chairman. It undertook during the next three days the revision and extension of the Skeleton Table of the Berlin Conference in the light of the new experimental and analytical data which were presented by the various delegates.

The skeleton table No. I adopted compares with the Berlin Conference Table as follows :

(*a*) The saturation pressure, enthalpy or total heat and specific volume of saturated liquid and saturated vapour are given at forty-two different temperatures — the Berlin Conference gave these values at ten different temperatures.

(*b*) The enthalpy or total heat and specific volume are given for seventy-two different states of superheated steam —the Berlin Conference gave these values at fifty-seven different states.

(*c*) The enthalpy or total heat and specific volume are given for eighty-seven different states of compressed liquid water—the Berlin Conference gave no values for the compressed liquid.

(*d*) At temperatures above 200° C. the tolerances on properties of saturated liquid and saturated vapour are reduced to 1/2 to 1/10 of the Berlin Conference values.

(*e*) Tolerances on the specific volume of superheated vapour at pressures above 100 kgr./sq. cm. are generally about 1/5 % of the volume—the Berlin Conference values were 1 to 3 %.

(*f*) Tolerances on enthalpy or total heat of superheated vapour are reduced to about 1/2 the Berlin Conference values.

The final session of the Conference was held on Saturday, September 22nd, at the American Society of Mechanical Engineers. Dr. Harvey N. Davis presided at this session in the absence of Dr. Dow. The report of the committee was presented by its chairman, Mr. Robinson, and was accepted by the Conference. The following resolutions were unanimously adopted :

Resolved : That it is the hope and desire of this Conference that the experimental investigation of the properties of water should be continued in order to utilise the equipment and *personnel* of the several contributing institutions to the best advantage. It is desired that the enthalpy or total heat measurements of superheated steam be continued at the Imperial College of Science, London, and in Czechoslovakia, and extended as far in the range of temperature and pressure as is practicable, and that other independent investigations of this field should be encouraged. The Conference records its appreciation of the assurances of the British delegation that this work will be carried out.

It is desired that new measurements of the saturation pressure of steam between 0 and 100° C. be undertaken at the Reichsanstalt, Berlin, and at the National Bureau of Standards, Washington, and the Conference records its appreciation of the assurance of the German delegation that their section of the work will be carried out. It is desired that Dr. Koch may be able to continue his measurements of the heat capacity of the liquid and gaseous phases of water.

It is desired that the measurements on the rate of change of enthalpy or total heat of superheated steam with pressure be continued at the Massachusetts Institute of Technology, Cambridge, and that the possibility of carrying out simi-

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(2) Deceased, October 2nd, 1934.

TABLE A. — **Pressure conversion table.**

Units.	Atm.	kg/cm².	Lb./in.².	Bar.	Mm. Hg.
1 atmos. . . .	1	1.033228	14.6959	1.013250	760
1 kgr./cm² . . .	0.967841	1	14.2233	0.980665	735.559
10 lb./in.² . . .	0.68046	0.70307	10	0.689476	517.149
1 bar	0.986923	1.019716	14.5038	1	750.062
1 m. Hg. . . .	1.31579	1.35951	19.3368	1.333224	1 000

TABLE B. — **Energy conversion table.**

Volume conversion factors : *Specific volume :*

1ft.³ = 28 316.8 cm³ = 28.3161 litres. 1 cu. ft./lb. = 0.062428 m³/kg. 1 m³/kg. = 16.0185 cu. ft./lb.

Units.	Joules.	Kg.-m.	Ft.-lb.	Int. J.	Int. whr.	I.T. cal.	B.Th.U.	lb./in.² ×ft.³.	Atm. ×dm³.
10⁴ Joules . . .	10 000.0	1 019.72	7 375.62	9 997.0	2.77694	2 388.17	9.4770	51.2196	98.6923
100 Kg.-m. . . .	980.665	100.0	723.30	980.371	0.272325	234.20	0.92938	5.02293	9.67841
10⁴ ft.-lb. . . .	13 558.2	1 382.55	10 000.0	13 554.1	3.7650	3 237.9	12.8491	69.4444	133.809
10⁴ Int. Joules .	10 003.0	1 020.02	7 377.8	10 000.0	2.7778	2 388.9	9.4799	51.235	98.722
10 Int. whr. . .	36 011.0	3 672.1	26 560.0	36 000.0	10.0	8 600.0	34.1275	184.446	355.40
10³ I.T. cal. . .	4 187.3	426.99	3 088.4	4 186.05	1.16279	1 000.0	3.9683	21.447	41.3255
10 B.Th.U. . . .	10 551.8	1 075.99	7 782.6	10 548.7	2.93019	2 519.96	10.0	54.046	104.138
10³ lb./in.²×ft³ .	195 238.0	19 908.7	144 000.0	195 179.0	54.216	46 626.0	185.027	1 000.0	1 926.85
100 Atm.×dm³	10 132.5	1 033.23	7 473.35	10 129.5	2.81374	2 419.8	9.6026	51.898	100.0

1 litre × atm. = 1.000027 atm. × dm³. 1 kgr./cm² × m³ = 10 000 Kg.-m.

TABLE I. — **Properties of saturated liquid water and saturated vapour.**

Temp. deg. Cent.	Pressure, kg./cm.²	Toler- ance, ±	Specific volume.				Enthalpy or total heat.			
			Liquid, cm.³/g.	Toler- ance, ±	Vapour, cm.³/g.	Toler- ance, ±	Liquid, I.T.Cal./g.	Toler- ance, ±	Vapour, I.T.Cal./g.	Toler- ance, ±
0	0.006228	0.000006	1.00021	0.00005	206 310	210	0*	0	597.3	0.7
10	0.012513	0.000010	1.00035	0.00010	106 410	110	10.04	0.01	601.6	0.7
20	0.023829	0 000020	1.00184	0.00010	57 824	58	20.03	0.02	605 9	0.6
30	0.043254	0.000030	1.00442	0.00010	32 922	33	30.00	0.02	610.2	0.5
40	0.075204	0.000038	1.00789	0.00010	19 543	19	39.98	0.02	614.5	0.5
50	0 12578	0.00006	1.0121	0.0002	12 045	12	49.95	0.03	618.9	0 5
60	0 20312	0.00010	1.0171	0.0002	7 678.3	7.7	59.94	0.03	623.1	0.5
70	0.31775	0.00016	1.0228	0.0002	5 046.3	5.0	69.93	0.03	627.3	0 5
80	0.48292	0.00024	1.0290	0.0002	3 409.2	3.4	79.95	0.04	631.4	0.5
90	0 71491	0.00036	1.0359	0.0002	2 361.5	2.4	89.98	0.05	635.3	0.5
100	1.03323	Nil	1.0435	0.0002	1 673.2	1.7	100.04	0.05	639.1	0.5
110	1.4609	0.0010	1.0515	0.0004	1 210.1	1.2	110.12	0.06	642.7	0.5
120	2.0245	0.0013	1.0603	0 0004	891.65	0.89	120.25	0.06	646.2	0.5
130	2.7544	0.0016	1.0697	0.0004	668.21	0.67	130.42	0.07	649.6	0.5
140	3.6848	0.0021	1.0798	0.0004	508.53	0.51	140.64	0.07	652.7	0.6
150	4.8535	0.0032	1.0906	0 0004	392.46	0.39	150 92	0.08	655.7	0.7
160	6.3023	0.0042	1.1021	0.0004	306.76	0.31	161.26	0.08	658.5	0.8
170	8.0764	0 0053	1.1144	0.0004	242.55	0.24	171.68	0.09	661.0	0.8
180	10.225	0.007	1.1275	0 0004	193 80	0.19	182.18	0.09	663.3	0.9
190	12.800	0.008	1.1415	0.0004	156.32	0.16	192.78	0.10	665.2	0.9
200	15.857	0.008	1.1565	0.0004	127.18	0.13	203.49	0.10	666.8	0.9
210	19.456	0.008	1.1726	0.0004	104.24	0.10	214.32	0.11	668.0	0.9
220	23.659	0.009	1.1900	0 0004	86.070	0.086	225.29	0 11	668.0	0.9
230	28.531	0.010	1.2087	0.0004	71.483	0.071	236.41	0.12	669.4	0.9
240	34.140	0.012	1 2291	0.0004	59.684	0.060	247.72	0 12	669.4	0.9
250	40.560	0.013	1.2512	0.0004	50.061	0.050	259.23	0.13	668.9	0.9
260	47.866	0.015	1.2755	0.0004	42.149	0.042	270.97	0.18	667.8	0.9
270	56.137	0.017	1.3023	0.0004	35.593	0.036	282.98	0.19	666.0	0.9
280	65.457	0.020	1.3321	0.0004	30.122	0.030	295.30	0.20	663.6	0.9
290	75.917	0.022	1.3655	0.0005	25.522	0.030	307.99	0.20	660.4	0.9
300	87.611	0.024	1.4036	0.0005	21.625	0.035	320.98	0.30	656.1	1.0
310	100.64	0.03	1.4475	0.0005	18.300	0 035	334.63	0.40	650.8	1.2
320	115.12	0.03	1.4992	0.0005	15.438	0.035	349.00	0.50	644.2	1.4
330	131.18	0.04	1.5619	0.0005	12.952	0.035	364.23	0.60	636.0	1.6
340	148.96	0.04	1.6408	0.0005	10.764	0.035	380.69	0.70	625.6	1.8
350	168.63	0.04	1.7468	0.0006	8.802	0.035	398.9	0.8	611.9	2.0
360	190.42	0.05	1.9066	0.0040	6.963	0.040	420.8	0.8	592.9	2.0
370	214.68	0.05	2.231	0.021	4.997	0.100	452.3	1.5	559 3	3.0
371	217.26	0.10	2.297	0.026	4.761	0.100	457 2	1.5	553.8	3.5
372	219.88	0.11	2.381	0.034	4.498	0.110	462.9	2.2	547.1	4.0
373	222.53	0.11	2.502	0.053	4.182	0.120	471.0	3.5	538.9	4.5
374	225 22	0.11	2.79	0.15	3.648	0.120	488	5	523.3	5.0

Observed values of critical temperature :
Massachusetts Institute of Technology 374.11 C.
Reichsanstalt 374.2±0.1 C.
* By definition.

TABLE II. — **Specific volume of compressed liquid water and superheated steam** (cm³ g.).

Of each pair of figures the upper represents the accepted value and the lower the tolerance (±).

Pressure, kg. per sq. cm.	Temperature, deg. Cent. 0	50	100	150	200	250	300	350	400	450	500	550
1	1.00016 0.00005	1.01210 0.00020	1 730.0 1.0	1 975.0 2.0	2 216.0 2.0	2 454.0 2.0	2 691.0 3.0	2 928.0 3.0	3 164.0 3.0	3 400.0 3.0	3 636.0 4.0	3 872.0 4.0
5	0.9999 0.0002	1.0119 0.0002	1.0432 0.0002	1.0906 0.0002	433.8 0.4	484.1 0.5	533.2 0.5	581.6 0.6	629.6 0.6	677.4 0.7	725.0 0.7	772.5 0.8
10	0.9997 0.0002	1.0117 0.0002	1.0431 0.0002	1.0902 0.0002	210.4 0.2	237.6 0.2	263.3 0.3	288.2 0.3	312.7 0.3	337.0 0.3	361.1 0.4	385.1 0.4
25	0.9989 0.0002	1.0110 0.0002	1.0422 0.0002	1.0893 0.0002	1.1556 0.0003	89.0 0.1	101.1 0.1	112.1 0.1	122.6 0.1	132.7 0.1	142.7 0.1	152.6 0.2
50	0.9977 0.0002	1.0099 0.0002	1.0409 0.0002	1.0877 0.0002	1.1532 0.0003	1.2495 0.0004	46.41 0.07	53.12 0.08	59.05 0.09	64.60 0.09	69.92 0.10	75.10 0.12
75	0.9965 0.0002	1.0088 0.0002	1.0397 0.0002	1.0861 0.0002	1.1508 0.0003	1.2452 0.0004	27.48 0.05	33.22 0.07	37.78 0.08	41.83 0.08	45.62 0.09	49.25 0.10
100	0.9952 0.0002	1.0077 0.0002	1.0385 0.0002	1.0845 0.0002	1.1485 0.0003	1.2410 0.0004	1.3979 0.0007	23.03 0.05	27.05 0.05	30.41 0.06	33.45 0.07	36.32 0.07
125	0.9940 0.0002	1.0067 0.0002	1.0372 0.0002	1.0829 0.0002	1.1462 0.0003	1.2369 0.0004	1.3877 0.0007	16.66 0.03	20.53 0.04	23.52 0.05	26.14 0.05	28.55 0.06
150	0.9929 0.0002	1.0056 0.0002	1.0360 0.0002	1.0814 0.0002	1.1439 0.0003	1.2330 0.0004	1.3782 0.0007	11.98 0.02	16.10 0.03	18.90 0.04	21.25 0.04	23.36 0.05
200	0.9905 0.0002	1.0035 0.0002	1.0337 0.0002	1.0784 0.0002	1.1395 0.0003	1.2255 0.0004	1.3612 0.0007	1.671 0.002	10.31 0.02	13.05 0.03	15.11 0.03	16.87 0.03
250	0.9882 0.0002	1.0015 0.0002	1.0314 0.0002	1.0755 0.0002	1.1353 0.0003	1.2184 0.0004	1.3462 0.0007	1.604 0.002	6.366 0.013	9.46 0.02	11.39 0.02	12.96 0.03
300	0.9859 0.0002	0.9995 0.0002	1.0291 0.0002	1.0726 0.0002	1.1312 0.0003	1.2117 0.0004	1.3327 0.0007	1.557 0.002	3.02 0.01	6.98 0.02	8.90 0.02	10.35 0.02
350	0.9837 0.0002	0.9975 0.0002	1.0269 0.0002	1.0698 0.0002	1.1272 0.0003	1.2054 0.0004	1.3207 0.0007	1.521 0.002				
400	0.9814 0.0002	0.9956 0.0002	1.0247 0.0002	1.0670 0.0002	1.1234 0.0003	1.1994 0.0004	1.3097 0.0007					

Compressed liquid water — — Superheated steam.

The specific volume of the liquid at 4°C, at a pressure of one atmosphere is 1.000027.

TABLE III. — **Enthalpy or total heat of compressed liquid water and superheated steam (I. T. cal./g.).**

Of each pair of figures the upper represents the accepted value and the lower the tolerance (±).

Pressure, kg /sq.cm.	Temperature, deg. Cent. 0	50	100	150	200	250	300	350	400	450	500	550
1	0.023 0.005	49.97 0.03	639.2 0.5	663.2 0.5	686.5 0.6	710.1 0.6	734.0 1.2	758 0 1.2	782.4 1 2	807.2 1.2	832.3 1.2	857.8 2.0
5	0 120 0.505	50.05 0.03	100.11 0.05	150.92 0.08	681.9 1.0	706.7 1.0	731.5 1.2	756.1 1.2	780.8 1.2	805.9 1.2	831.3 1.2	856.9 2.0
10	0.240 0.005	50.15 0.03	100.20 0.05	151.00 0.08	675.1 1.0	702.1 1.1	728.0 1.2	753.5 1.2	778.9 1.2	804.5 1.2	830.1 1.2	855.9 2.0
25	0.599 0.005	50.45 0.03	100 46 0.05	151.21 0.08	203.6 0.1	687.8 1.1	718.0 1.2	746.3 1.2	773.3 1.2	800.0 1.2	826.5 1.2	852.6 2.0
50	1.20 0.01	50.96 0.03	100.90 0.05	151.58 0 08	203.8 0.1	259.2 0.1	698.4 1.2	732.9 1.2	763.1 1.2	791.6 1.2	819.9 1.2	847.3 2.0
75	1.79 0.01	51.46 0.03	101.34 0.05	151.95 0.08	204.1 0.1	259.2 0.1	672.6 1.2	717.6 1.2	752.1 1.2	783.2 1.2	813.1 1.2	841.8 2.0
100	2.39 0.01	51.96 0.03	101.78 0.05	152.32 0 08	204.3 0.1	259.2 0.1	320.5 0.3	699.5 1.2	740.0 1 3	774.5 1.3	806.0 1.3	836.1 2.0
125	2.98 0.01	52.46 0.03	102.22 0.05	152.69 0.08	204.6 0 1	259.3 0.1	319 9 0.3	676.7 1.2	726.9 1.3	765.2 1 3	799.1 1.3	830.3 2.0
150	3.57 0.01	52.96 0.03	102.65 0.05	153.06 0.08	204.8 0.1	259.3 0.1	319.3 0.3	648.2 1.5	712.1 1.3	755.3 1.3	791.8 1.3	824.4 2.0
200	4.74 0.01	53.96 0.03	103.57 0.05	153.82 0.08	205.2 0.1	259.4 0.1	318.4 0.3	393 1 0.8	676.5 2.0	733.4 2.0	776.0 2.0	812.0 2.5
250	5.90 0.01	54.96 0.03	104.46 0.05	154.57 0.08	205.8 0.2	259.5 0.2	317.6 0.3	387.6 0.8	622.5 2.5	707.5 2.5	758.8 2.5	798.9 3.0
300	7.05 0.01	55.96 0.03	105.35 0.05	155.33 0.08	206.2 0.3	259.7 0.3	317.0 0.3	384.0 0.8	524.5 3.0	677.5 2.5	739.7 2.5	

Compressed liquid water —— | —— Superheated steam.

lar measurements on the liquid phase be likewise considered, and the Conference records its appreciation of the assurances of the Massachusetts Institute of Technology representatives that this work will be carried out.

It is desired that new measurements of the enthalpy or total heat of water between 0 and 100° C. be undertaken at the National Bureau of Standards to provide greater accuracy in these values for use in other calorimetric measurements.

It is further desired that additional measurements of latent heat between 0 and 50° C. be undertaken at the National Bureau of Standards to complete the series of these values.

An invitation extended by the Masaryk Academy of Work to hold the Fourth International Steam Tables Conference in Prague, Czechoslovakia, was accepted by unanimous vote of the Conference. In accordance with precedent established at the London and Berlin Conferences, the Secretariat will be transferred from the American Society of Mechanical Engineers to the Masaryk Academy of Work when the business of the Third Conference is completed.

The Skeleton Table adopted by the Third International Steam Tables Conference, which supersedes the Berlin Conference Table of 1930, is given herewith. The limits fixed by its accepted values and tolerances constitute a criterion, internationally agreed upon, by which the reliability of a steam table may be judged.

SKELETON TABLE ADOPTED BY THE THIRD INTERNATIONAL STEAM TABLES CONFERENCE, SEPTEMBER 1934.

UNITS AND CONVERSION FACTORS.

Definitive values :

1. Length : 2.54000 cm. = 1 inch.

2. Mass : 453.5924 grammes = 1 lb.

3. Pressure :

(*a*) One standard atmosphere = pressure of 76 cm. mercury column (density 13.5951 g./cm^3, gravity 980.665 cm./sec.^{2}).

(*b*) One bar = 10^6 dynes per cm^2.

4. Energy :

(*a*) 1 000 international steam table calories (I.T. cals.) = 1/860 international kilowatt hour.

(*b*) 1 international electrical watt = 1.0003 absolute watts.

(*c*) 1 British thermal unit = 251.996 I.T. cal.

5. Temperature :

All temperatures are expressed in terms of the International Temperature Scale. Where Kelvin temperatures were used the values were obtained by adding 273.16 to the temperatures on the International Scale.

On the basis of the above values the conversion tables A and B have been derived.

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